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Turbidity Removal for Small Public Water Systems

SMC Martin, Inc., Valley Forge, PA

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This document has been prepared to aid water utility owners, engineers, managers and operators in understanding and dealing with excess turbidity levels in the water supply. It is intended to be used for defining the problem, developing and evaluating proposed solutions, explaining to utility customers the need for turbidity control, and understanding operational considerations. Finally, it explains a method to estimate the costs associated with installation and operation of turbidity removal systems.

This document contains no regulatory policy and does not obligate systems to use any treatment or nontreatment technique to reduce turbidity concentrations.

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Turbidity Removal for Small Public Water Systems

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TURBIDITY REMOVAL FOR
SMALL PUBLIC WATER SYSTEMS

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TABLE OF CONTENTS

Page

I. SUMMARY AND OVERVIEW I-1
Purpose and Structure of This Manual I-1
When Turbidity is a Problem. I-2
Alternative Methods Used to Reduce Excess Drinking Water Turbidity I-2
Cost Estimating Procedures and Funding Sources I-5
Operation and Maintenance. I-5
Summary. I-6

II. INTRODUCTION II-1
Definition & Causes of Turbidity II-1
Significance of Turbidity to Human Health. II-2
The Safe Drinking Water Act. II-2
Sampling and Analyzing for Turbidity II-7

III. MEASURES TO TAKE IF THE TURBIDITY IS EXCESSIVE III-1

Introduction III-1
Nontreatment Alternatives. III-1
Treatment Alternatives for Turbidity Removal III-3
Presettling. III-5
Coagulation. III-5
Flocculation III-14
Sedimentation. III-15
Filtration III-17
Packaged Treatment Systems III-25
Direct Filtration. III-30
Waste Management III-30

IV. DESIGNING TURBIDITY REMOVAL SYSTEMS. IV-1
Introduction IV-1
Characterization IV-1
Process and Equipment Selection. IV-4
Monitoring and Control IV-10
Waste Disposal IV-11
Corrosion Prevention IV-11
Other Design Considerations. IV-13

V. COST ESTIMATING PROCEDURES AND FUNDING SOURCES V-1
Construction Costs V-1
Operation & Maintenance Costs. V-9
Funding Sources. V-14

VI. OPERATION AND MAINTENANCE. VI-1
Operator Requirements. VI-1
Manuals, Equipment and Supplies Needed VI-1
Startup Training and Assistance. VI-2
Monitoring VI-2
Coagulation Control and Monitoring VI-3
Preventive Maintenance VI-4

TABLE OF CONTENTS
(Continued)

Page

Emergency Procedures VI-7
Safety Procedures. VI-7

VII. CASE HISTORIES VII-1
Carlisle, Pennsylvania .VII-1
Hancock, Maryland. VII-3
Direct Filtration - 17 Plant Survey. VII-8

REFERENCES

Appendices:

A: Metric-English Conversion Factors
Abbreviations and Symbols. A-1

B: Sample Turbidity Meter Specification B-1

C: Jar Test Procedure C-1

D: Preventive Maintenance for Aquarius A Series
Complete Treatment Plant D-1

LIST OF FIGURES

Number	Title	Page
1	Nontreatment and Treatment Alternatives for Turbidity Removal.	I-3
2	Water Treatment Processes for Turbidity Removal.	I-3
3	Typical Packaged Complete Treatment Plant.	I-4
4	Typical Sources of Turbidity in Surface Waters . . .	II-1
5	Protected and Exposed Micro-Organisms.	II-3
6	Turbidity Sampling Points for a Small Water System Using Surface Waters.	II-7
7	Comparison of Nephelometric and Jackson Candle Turbidity Measurement	II-9
8	Nontreatment and Treatment Alternatives for Meeting NIPDWR Turbidity Standards	III-2
9	Turbidity Removal from Drinking Water.	III-4
10	Coagulation/Flocculation/Sedimentation/Filtration. .	III-6
11	Mechanisms of Chemical Coagulation	III-6
12	Jar Test Apparatus	III-11
13	Chemical Dissolving and Feeding Equipment.	III-13
14	Some Rapid Chemical Mixers	III-13
15	Flocculators	III-16
16	Clarifiers	III-16
17	Clarifier/Flocculator.	III-18
18	Tube Clarifier	III-18
19	Principal Mechanisms of Filtration	III-19
20	Typical Rapid Sand Filter.	III-21
21	Filter Configurations.	III-22
22	Ideal Filter	III-23
23	Mixed Media Filter	III-24
24	Pressure Filter.	III-24
25	Diatomaceous Filter Septum	III-27
26	Pressure Diatomite Filter.	III-28
27	Packaged, Complete Treatment System.	III-29
28	Direct Filtration vs. Conventional Process Design	III-31
29	Design Process for Turbidity Control Systems	IV-2
30	Treatment Process Selection.	IV-5
31	Site Plan of 250,000 gpd Packaged Complete Treatment Plant with Waste Lagoons	IV-12
32	Construction Cost for Package Gravity Filtration Plants.	V-6
33	Construction Cost for Package Pressure Diatomite Filters.	V-7
34	Construction Costs for Package Complete Treatment Plants	V-8
35	Construction Costs for Sludge Dewatering Lagoons.	V-10
36	Annual Labor Hours for Package Gravity Filters . . .	V-13

LIST OF FIGURES
Continued

Number	Title	Page
37	Annual Labor Hours for Packaged Pressure Diatomite Filters.	V-13
38	Operation and Maintenance Cost of Packaged Complete Treatment Plants - Building Energy, Process Energy and Maintenance Material.	V-17
39	Annual Labor Hours for Packaged Complete Treatment Plants	V-18
40	Sample Coagulant Control Curves.	VI-3
41	Equipment Inventory Sheet.	VI-5
42	Equipment Data Sheet	VI-6
43	Maintenance Procedure Sheet.	VI-8
44	Weekly Preventive Maintenance Schedule	VI-9
45	Report of Trouble/Corrective Action Form	VI-10
46	Carlisle, PA Packaged Complete Treatment System. . .	VII-2
47	Hancock, MD Packaged Complete Treatment System . . .	VII-5

LIST OF TABLES

Number Title Page

1 Federal Financial Assistance Programs I-6
2 Some Waterborne Illnesses and Causitive Agents . . . II-3
3 Sample Turbidity Data Form II-6
4 Partial List of Nephelometric Turbidity Meter Suppliers II-9
5 Commonly Used Coagulating Agents III-7
6 Partial List of Coagulant Suppliers III-10
7 Partial List of Gravity and Pressure Sand Filter Suppliers III-26
8 Partial List of Diatomite Filter Vendors III-27
9 Summary of Complete Treatment Design Data For Packaged and Custom Designed Systems IV-9
10 System Design Approach For Small Water Systems . . . IV-14
11 Package Gravity Filter Plants Design Concept V-4
12 Itemized Construction Costs for Package Gravity Filter Plants V-6
13 Itemized Construction Costs for Package Pressure Diatomite Filters V-7
14 Itemized Construction Costs for Package Complete Treatment Plants V-8
15 Itemized Construction Costs for Sludge Dewatering Lagoons V-10
16 Capital Recovery Factors for Some Combinations of Interest (i) and Project Life (n) V-11
17 Operation and Maintenance Summary for Package Gravity Filter Plants V-12
18 Operation and Maintenance Summary for Package Pressure Diatomite Filters V-15
19 Operation and Maintenance Summary for Package Complete Treatment Plants V-16
20 Sample Cost Analysis for a 140 gpm Complete Treatment Plant V-21
21 Carlisle Suburban Authority, Pennsylvania Plant Data VII-4
22 Hancock, Maryland Plant Data VII-7

I. SUMMARY AND OVERVIEW

PURPOSE AND STRUCTURE OF THIS MANUAL

This document has been prepared to aid water utility owners, engineers, managers and operators in understanding and dealing with excess turbidity levels in the water supply. It is intended to be used for defining the problem, developing and evaluating proposed solutions, explaining to utility customers the need for turbidity control, and understanding operational considerations. Finally, it explains a method to estimate the costs associated with installation and operation of turbidity removal systems.

This handbook is designed as a technical guide to turbidity removal for those smaller size systems that have decided that turbidity control is desirable. This document contains no regulatory policy and does not obligate systems to use any treatment or nontreatment technique to reduce turbidity concentrations. If appropriate, those regulatory requirements are or will be established by the primacy agency as part of its implementation of the Primary Drinking Water Regulations.

The handbook is divided into seven sections, plus references and an Appendix, as follows:

Section	
I	**Summary and Overview**
II	**Introduction** - discusses sources of turbidity in drinking water, health effects, federal drinking water regulation, and methods for turbidity analysis in drinking water.
III	**Nontreatment and Treatment Alternatives** - different approaches to solving excess turbidity problems.
IV	**Design of Turbidity Removal Systems** - turbidity removal system types and some suppliers; design factors and suggested specification items.
V	**Cost estimating procedures and Funding Sources**- Provides a method for determining capital and operation and maintenance costs; sources of loans, grants and other financial assistance.
VI	**Operation and Maintenance** - guidelines for setting up and running O&M and monitoring programs.
VII	**Case Histories** - experiences of several utilities which are removing excess turbidity from drinking water supplies.

This document is written for the owners, engineers and operators of smaller water systems, serving up to 6,000 persons at a flow rate of up to 500,000 gallons per day (1892.5 cu.m./day). Although the information contained herein may be useful to larger utilities, it is intended primarily to support the water quality improvement efforts of smaller utilities that may lack the technical and financial resources of the larger systems.

This document is not intended as a substitute for professional advice for site-specific problems. These should be approached in consultation with the state agency having primary enforcement responsibility for the SDWA and competent professional engineers.

The abbreviations and units used in this document are defined in Appendix A.

WHEN TURBIDITY IS A PROBLEM

The term **turbidity** is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a liquid sample. In water, it is caused by the presence of suspended matter (e.g., clay, silt, algae). Typically, water sources become turbid as a result of erosion, waste discharges, aquatic weeds and algae, and decay of surface vegetation which falls or is washed into the water.

Generally, moderate amounts of turbidity are not a direct health hazard. However, turbidity can interfere with the action of disinfectants thereby allowing disease causing organisms in the water to survive and multiply. For this reason, it is important to control turbidity in public water supplies. Accordingly, the National Interim Primary Drinking Water Regulations (NIPDWR), resulting from the 1974 Safe Drinking Water Act, specify average monthly and two-day maximum turbidity levels of 1 NTU* and 5 NTU* respectively. To meet these standards, most surface waters and some ground waters require treatment.

ALTERNATIVE METHODS USED TO REDUCE EXCESS DRINKING WATER TURBIDITY

Figure 1 depicts the nontreatment and treatment alternatives discussed in this Manual. Treatment for turbidity removal can involve significant costs. Therefore, nontreatment alternatives deserve close scrutiny before a treatment plant is selected. For example, it may be possible to switch from surface to ground water sources of acceptable turbidity. Alternatively, your system might join with other systems in an existing or new regional system, thereby benefitting by economies of scale in plant construction and operation.

Whether you use a packaged (premanufactured) or custom designed and constructed** plant, it will probably feature the processes shown in Figure 2. Process elements are as follows:

- **Coagulation** - Addition of relatively small quantities of coagulating chemicals to a turbid water will cause finely divided solids to clump together, or coagulate, aiding in their removal in subsequent processes. The chemicals must be completely and rapidly mixed with the influent water to most effectively meet this objective.
- **Flocculation** - Gently stirring coagulated waters

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* Nephelometric Turbidity Units.

** The term "custom" used here describes plants that have each stage of the process individually designed and constructed.

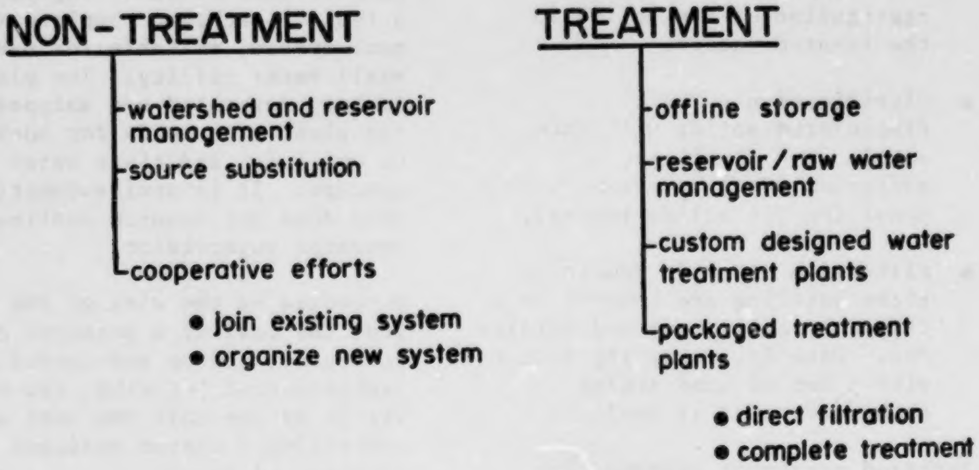

NON-TREATMENT
watershed and reservoir management
source substitution
cooperative efforts
join existing system
organize new system
TREATMENT
offline storage
reservoir / raw water management
custom designed water treatment plants
packaged treatment plants
direct filtration
complete treatment

Figure 1. Nontreatment and Treatment Alternatives for Turbidity Removal

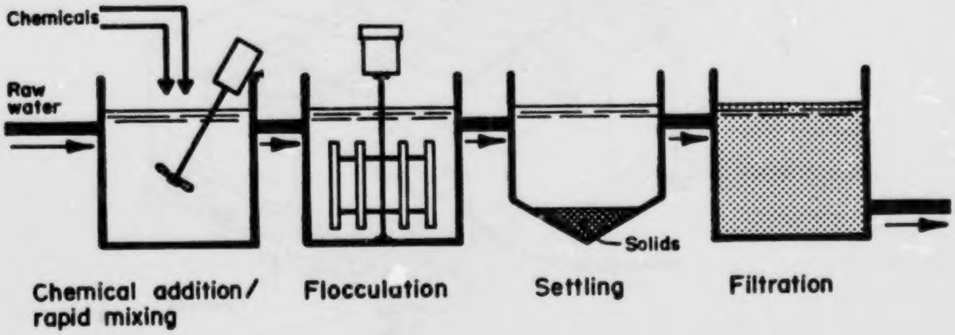

Chemicals
Raw water
Solids
Chemical addition/ rapid mixing
Flocculation
Settling
Filtration

Figure 2. Water Treatment Process for Turbidity Removal

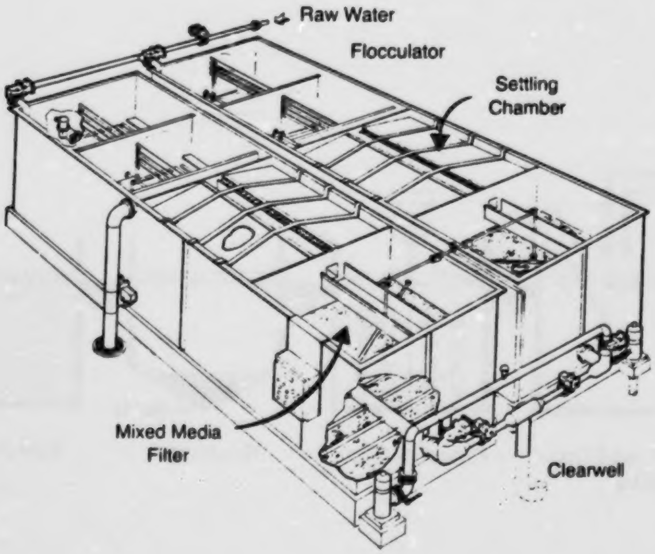
under controlled conditions (flocculation) causes further aggregation of the solids in the treated waters.

- **Clarification** - The flocculated solids will then settle in a clarifier, a quiescent settling vessel with provision for solids removal.
- **Filtration** - Solids remaining after settling are removed in a filter by entrapment and straining. Usually, a gravity filter with a bed of sand and/or anthracite coal is used.

Packaged treatment systems, for **direct filtration or complete treatment** are generally the most economical for small water utilities. Direct filtration should only be used where close operator supervision can be provided. Otherwise, packaged complete treatment is recommended. Figure 3 is a typical packaged complete treatment system, suitable for use by a small water utility. The plant is factory assembled and shipped to the plant site ready for hook up to utilities and clear water storage. It is semi-automatic and thus does not require continuous operator supervision.

Depending on the size of the facility, the cost of a packaged plant, delivered, set up and housed in a prefabricated building, can be as little as one-half the cost of installing a custom designed and constructed plant.

Operation and maintenance (O&M) costs are also somewhat reduced due to the simplicity, serviceability and automated features of packaged plants.



Courtesy: NEPTUNE
Microfloc, Inc.

Figure 3. Typical Packaged Complete Treatment Plant

Selection of the appropriate packaged system begins with fully defining the application. For example:

- **Water quality** - characteristics of the water source including quality and variability of suspended and dissolved solids, turbidity, alkalinity and hardness, and presence of significant color levels.
- **Plant size** - hourly, daily, weekly and annual flow and seasonal variation; expected future demand growth.
- **Site constraints** - available land area and topography, climate, special waste disposal problems.
- **Available O&M Resources** - availability (hours per day and per week) and skill levels of plant operators, and basic laboratory facilities for process monitoring.

Turbidity removal processes generate waste which must be disposed of properly. Typically, coagulation and settling processes require disposal of dilute gelatinous sludge. Filter backwashing (cleaning) produces several thousand gallons per day of turbid wash water at the average 250,000 gpd (946.2 cu.m./d) plant. Settling and recirculation of clear water, discharge to local sewers, sludge hauling to landfill, lagooning and sand drying beds are some waste management approaches used by small water systems.

In some cases, it is possible to reduce the size and cost of turbidity removal systems by protective supervision and maintenance of your watershed. Supervision of development and agricultural activities to limit erosion on the watershed is one example of watershed management. If your system is equipped with off stream raw water storage, you could reduce treatment costs by switching from river intakes to stored supplies during episodes of high turbidity, such as might occur after heavy rains.

COST ESTIMATING PROCEDURES AND FUNDINC SOURCES

Section V explains a procedure that can be used for estimating treatment and operation and maintenance costs.

Costs cited in the examples and cost curves provided in this handbook are estimated data generated from a variety of sources. Adjusting cost figures for inflation is also discussed in Section V.

Sources of financial assistance in the form of loans, loan guarantees, or outright grants are very limited. The principal federal financial assistance programs available are shown in Table 1.

OPERATION AND MAINTENANCE

Operator requirements for turbidity removal systems depend on the plant size, raw water characteristics, and equipment selected. Packaged systems are generally semi-automatic, freeing the plant operator to carry out routine or repair maintenance. These systems are also usually designed to allow for intermittent operation. Thus, you may be able to schedule water production for one or two shifts daily, or only during weekdays, reducing operator costs.

TABLE 1

FEDERAL FINANCIAL ASSISTANCE PROGRAMS

Agency	Program Description
Farmers Home Administration	1. Cooperative grants up to 75 percent of project cost for publicly owned rural systems serving fewer than 10,000 persons. 2. Loan gurantees up to 90 percent of loan face value for public or private rural utilities, emphasizing those serving fewer than 2500 persons. 3. Direct loans up to 75 percent of project cost.
Department of Interior	1. Direct loan programs for non-federal entities in the 17 western states. 2. Financial assistance for systems serving American Indians.
Department of Housing and Urban Development	1. Community Block Development Grant Program.

Plant operators need to be properly trained. For systems using complete treatment, this includes control and monitoring of coagulation. This requires good basic understanding of coagulation chemistry and test methods for alkalinity, pH and turbidity. Knowledge of disinfection techniques and ability to measure disinfectant application rates and residuals is also necessary.

Selection of a packaged treatment system should include a thorough review of spare parts and specialized service needs. Do not purchase a plant from a vendor who cannot supply service support and shipment of critical spare parts on short notice. Chemical feed equipment and instrumentation are particularly important. A servicing representative should be available on short notice, as the utility's servicemen may not be qualified to repair this equipment. Stock all recommended chemical feed system spare parts. Provide specific training to operators on routine maintenance and repair, and make sure that several copies of detailed service manuals are available on site.

SUMMARY

Systems faced with the need to reduce excessive turbidity in the water supply can use a variey of nontreatment approaches, or install a treatment system. This handbook describes the design rationale used for developing a simple, reliable and cost effective system for turbidity control. Suggestions for nontreatment approaches by individual water utilities are also offered and a reference that discusses regionalization options in detail is provided.

II. INTRODUCTION

DEFINITION AND CAUSES OF TURBIDITY

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight[3] lines through a liquid sample.

Turbidity in water is caused by any suspended matter which interferes with the clarity of the water. This may include clay or silt, algae, and other organic or inorganic compounds.

Typical sources of turbidity in drinking water include the following (See Figure 4):

- Waste discharges.
- Runoff from disturbed or eroding watersheds.
- Algae or aquatic weeds and products of their breakdown in water reservoirs, rivers, or lakes.
- Humic acids and other organic compounds resulting from decay of plants, leaves, etc. in water sources.
- High iron concentrations which give waters a rust red coloration.

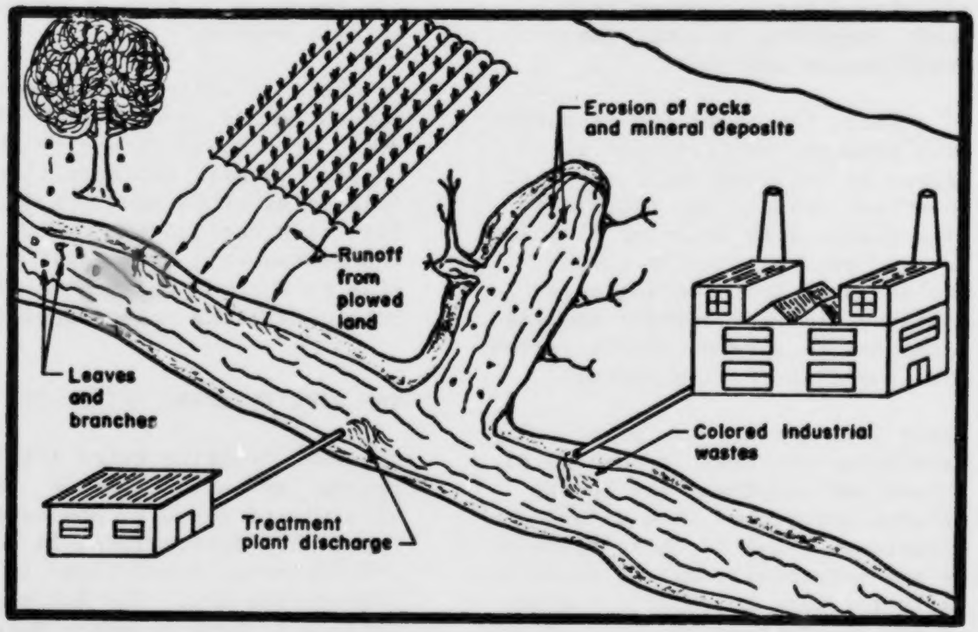

Erosion of rocks and mineral deposits
Runoff from plowed land
Leaves and branches
Colored industrial wastes
Treatment plant discharge

Figure 4. Typical Sources of Turbidity in Surface Waters

SIGNIFICANCE OF TURBIDITY TO HUMAN HEALTH

Excessive turbidity in drinking water is not only unsightly, but also may be a health hazard:

- Turbidity can provide food for microbes, promoting their regrowth in the distribution system.
- Turbidity interferes with ion exchange and carbon adsorption processes, and may interfere with laboratory analysis of water quality.
- Turbidity causing suspended particulate matter can absorb toxic substances, providing a medium to concentrate and transport these substances.

Of greatest concern, **turbidity can interfere with disinfection, allowing disease causing pathogenic organisms to enter the distribution system.**

In effect, the particles of turbidity provide "shelter" for microbes by reducing their exposure to attack (Figure 5). Turbidity also reacts with chlorine disinfectants directly, causing quick depletion of disinfecting power, possibly allowing disease causing pathogens to survive and be passed into the distribution system.

Table 2 summarizes the principal waterborne diseases, mechanism of attack and symptoms, and health effects associated with waterborne organisms. Many of these illnesses are potentially fatal, particularly for more vulnerable members of the population: the very young or old, or those in poor health for other reasons. There is no "safe" level of microbial pollution in drinking water. A dose which may not cause infection in one person may cause fatal illness in another, even though both are similar in age, background and physical health.

For a more detailed discussion of waterborne illness and disinfection techniques, the reader is referred to the following publication: "Micro-organism Removal for Small Water Systems." It has been prepared as a companion to this document and is available from the U.S. Environmental Protection Agency, Office of Drinking Water, 401 M Street, SW, Washington, DC 20460.

Turbidity from decaying vegetation can react with free chlorine to form **trihalomethanes,** compounds that have been implicated in human cancer. One of the trihalomethanes, **chloroform** is a particularly toxic by-product of the reaction of free chlorine and organic turbidity.

Asbestos, a mineral fiber which occurs naturally over much of the U.S., will cause turbidity when present in high concentrations. Inhaled asbestos has been identified as a carcinogen (cancer causing substance); therefore, it is wise to control and remove it from public drinking water supplies.

THE SAFE DRINKING WATER ACT

The Safe Drinking Water Act (SDWA) became law on December 16, 1974. It mandated the U.S. Environmental Protection Agency (EPA) to develop and implement regulations to enforce the Act. The **National Interim Primary Drinking Water Regulations (NIPDWR)** resulted from this mandate. The regulations are being implemented in two steps:

TABLE 2
SOME WATERBORNE ILLNESSES AND CAUSATIVE AGENTS*

Illness	Agent
Typhoid Fever	Salmonella typhi, (bacterium)
Paratyphoid Fever	Salmonella paratyphi, (bacterium)
Bacillary Dysentery	Shigella species, (bacterium)
Cholera	Vibrio cholerae, (bacterium)
Amoebic Dysentery	Endamoeba histolytica, (protozoan)
Infectious Hepatitus	Hepatitus A Agent, (virus)
Giardiasis	Giaridia lamblia, (protozoan)
Gastroenteritis	Rotavirus, Norwalk Agent, (viruses) Campylobacter Jejuni, Yersinia Enterocoliticus, (bacterium) As well as other bacteria and viruses.

*From "Micro-organism Removal For Small Water Systems."

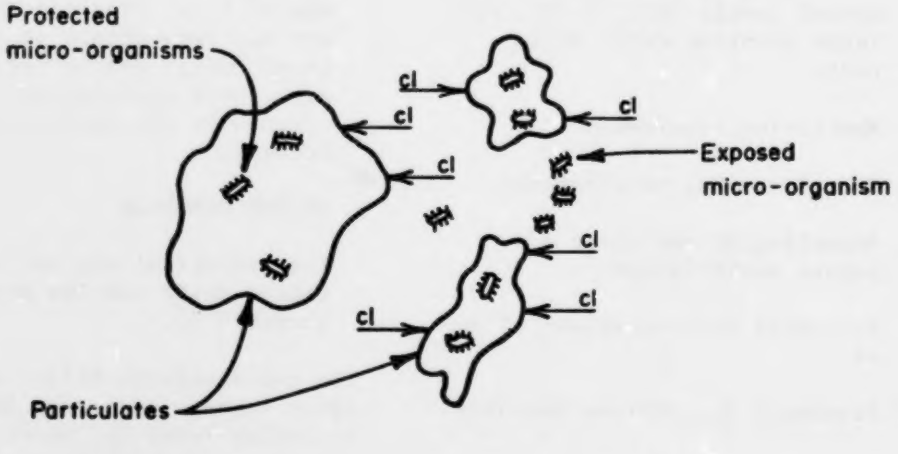

Protected
micro-organisms
cl
cl
cl
cl
Exposed
micro-organism
cl
cl
cl
Particulates

Figure 5. Protected and Exposed Micro-Organisms[4]

- The interim (initial) regulations, which became effective June 24, 1977.
- The revised regulations; changes to the regulations as health studies and treatment technology reviews on various contaminants are completed.

A **public water system** is defined in the NIPDWR and can be described as follows:

> ANY PUBLICLY OR PRIVATELY OWNED DRINKING WATER SUPPLY WITH AT LEAST 15 SERVICE CONNECTIONS, SERVING AT LEAST 25 PERSONS FOR A MINIMUM OF 60 DAYS PER YEAR.[5]

The NIPDWR applies to both **community** and **noncommunity** water systems. Community systems serve people during the entire year. Noncommunity systems serve travelers or other intermittent users.

Eight major provisions of the NIPDWR are of particular concern to the small water utility:

- Definition of Maximum Contaminant Levels (MCL's) for regulated drinking water pollutants
- Monitoring requirements
- Record keeping requirements
- Reporting to the state and public notification
- Variances and exemptions allowed
- Framework for citizen lawsuits
- Emergency powers
- Site requirements

Note that the NIPDWR are **Federal regulations**; individual states may also have primary drinking water regulations. These must be at least as stringent as the Federal regulations, and can also be more stringent.

NIPDWR Standards for Turbidity

The NIPDWR standards for turbidity are defined below. These standards apply to **surface waters only**. There is currently no direct standard for ground waters; however, use of these standards as guidelines for all water sources will help assure the delivery of safe potable water to the utility's customers.

FIRST STANDARD:

The monthly average of all turbidity samples must not exceed 1 Turbidity Unit (TU). This is the maximum contaminant level (MCL) established by EPA and published in Section 141.13 of the NIPDWR.

At state option, the monthly average can be raised to a maximum of 5 TU, provided the operator can demonstrate no increase in microbial contamination or a measurable disinfectant demand created by the particulates present.

SECOND STANDARD

The average of any two consecutive daily samples must not exceed 5 TU.

The two standards define an acceptable average operating level and an action level for short term occurences of high turbidity that might lead to ineffective disinfection.

Note that these standards alone do not assure that the water will be microbiologically safe. Adequate disinfection is also required. Some organisms, such as Giardia cysts (Protozoa) can pass through granular media filters and be present even where turbidity is 1 NTU or less. Giardiasis in humans, a dysentery like illness, may result if treatment and disinfection are inadequate to remove or kill the cysts.

NIPDWR Sampling and Analysis Requirements

Turbidity sampling requirements are outlined in Section 141.22 of the NIPDWR. They require daily turbidity samples for systems using surface water. This applies to both community and noncommunity systems. At state option, ground water users may be required to sample regularly for turbidity as well.

The samples must be taken at the point that the treated and disinfected water **enters the distribution system.** This must be done wherever a different treated surface water enters the system. Figure 6 depicts an example of these requirements. In addition to routine sampling, check samples are required if the maximum contaminant level exceeds the limit. The check sample should be taken within 1 hour. If this sample also exceeds the limit, you must report to the state within 48 hours.

The NIPDWR currently recognizes only one method of turbidity analysis, the **nephelometric** method. Results are reported as Turbidity Units (TUs) or nephelometric turbidity units (NTUs). An explanation of this method and how it compares with other turbidity measures is given later in this Section.

NIPDWR Recordkeeping and Reporting Requirements

Reporting and recordkeeping requirements are outlined in Sections 141.31 and 141.33 respectively of the NIPDWR.

The NIPDWR requires public water systems to keep a daily record of turbidity measurements and to retain, at minimum, a summary of test results for 10 years. Records of any variances or exemptions granted for turbidity must be retained for 5 years after their expiration. Any actions taken to correct a turbidity violation must be recorded and filed for at least 3 years following the last recorded action.

Table 3 from Reference 5 is a sample turbidity record form. It can be used to set up a turbidity record or it can be adapted to meet any specialized need. In any case, this form provides space for all of the information needed to be recorded from daily turbidity analyses and any additional check samples.

The NIPDWR requires two types of reporting by public water utilities:

- Reporting to the State
- Public notification

The state receives routine and check sampling and analysis reports, plus violation reports. Public notification via mail, newspaper, and radio/television may be required for violations of the MCLs or monitoring requirements.

Table 3[5]
Sample Turbidity Data Form

		Routine Sample		Check Sample			Two-Day Average of Turbidity		
Date	Sampled by Loc	Time	Value(TUs)(a)	Time	Value(TUs)	Value Used in Two-Day and Monthly Average(b)	Days	Average Value (TUs)(c)	
1	2	3	4	5	6	7	8	Sum 9	Avg 10
1									
2							1 - 2		
3							2 - 3		
4							3 - 4		
5							4 - 5		
6							5 - 6		
7							6 - 7		
8							7 - 8		
9							8 - 9		
10							9 - 10		
11							10 - 11		
12							11 - 12		
13							12 - 13		
14							13 - 14		
15							14 - 15		
16							15 - 16		
17							16 - 17		
18							17 - 18		
19							18 - 19		
20							19 - 20		
21							20 - 21		
22							21 - 22		
23							22 - 23		
24							23 - 24		
25							24 - 25		
26							25 - 26		
27							26 - 27		
28							27 - 28		
29							28 - 29		
30							29 - 30		
31							30 - 31		

TOTAL ________

MONTHLY AVERAGE (d) $\frac{\text{TOTAL TUs}}{\text{\# Days in Month}}$ ________

WATER SYSTEM ID#

____
Name of Water Supply

____
Location

MONTH

Type of Instrument used

(a) If value exceeds 1 TU take check sample within one hour

(b) Use values from original samples on days MCL was not exceeded and check sample values for days the MCL was exceeded

(c) To calculate The two-day average = $\frac{\text{DAY 1 TU + DAY 2 TU}}{2}$

(d) If monthly average is more than 1 TU, report to state and notify the public

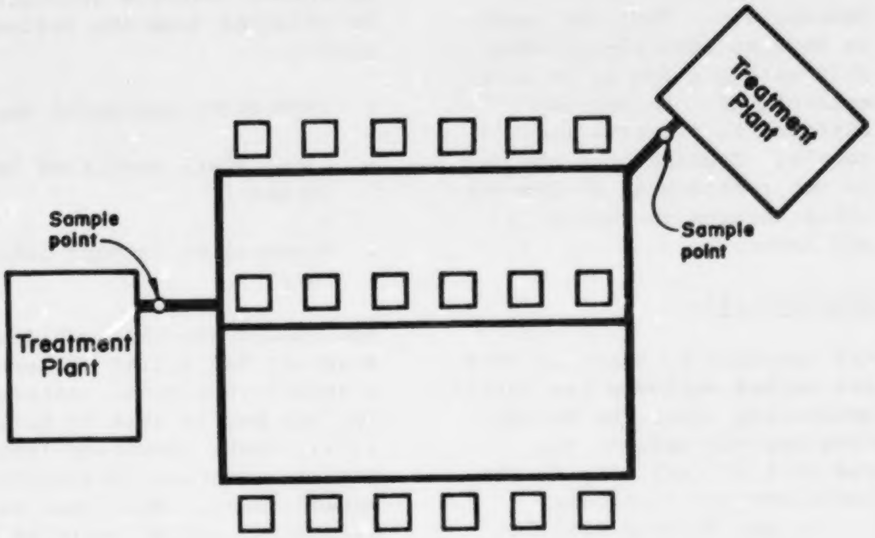


Figure 6. Turbidity Sampling Points for a Small Water System Using Surface Waters

Recommended Reading

A complete synopsis of the NIPDWR requirements, including MCL's, sampling and analysis, reporting and recordkeeping is available from the American Water Works Association:

> The Safe Drinking Water Act--Self Study Handbook, Community Water Systems, American Water Works Association, 6666 W. Quincey Avenue, Denver, Colorado 80235

It provides information on compliance with the Federal drinking water regulations. For answers to specific questions, contact the agency having primary enforcement responsibility within your State.

SAMPLING AND ANALYZING FOR TURBIDITY

Turbidity Sampling

Since the turbidimeter will detect any interference in the light path regardless of source, cleanliness of sample bottles and strict adherence to standard procedures are required for accurate analysis. These sampling procedures should be followed closely:

1. Use a clean, widemouth container specifically designed for water sampling. Glass or polyethylene bottles with plastic sealing lids are recommended.
2. Rinse the sample container 2 to 3 times with free flowing water from the sample tap before taking the sample.

3. Take the sample and cap it immediately. Test the sample as soon as possible (preferably within a few hours after collection). Do not add anything to preserve the sample. Storage over one day is not recommended as irreversible changes in turbidity may occur.

Turbidity Analysis

As noted previously, there is only one test method approved for turbidity monitoring under the NIPDWR: The nephelometric method. The measured unit of turbidity is the NTU (nephelometric turbidity unit). You may be more familiar with the older Jackson candle turbidimeter. This device, still in widespread use for various water and wastewater uses, measures turbidity in terms of Jackson Turbidity Units (JTUs). The basic difference between the units is shown in Figure 7. The nephelometric unit measures the light **scattered** at right angles by the sample; the Jackson Candle turbidimeter measures both the scattered and direct light as viewed through the sample. There is no general correlation between the NTU and the JTU. All NIPDWR standards and EPA documents that refer to Turbidity Units (TUs) are using NTU measurements.

To measure NTUs you will need a nephelometric turbidimeter and standard solutions which are used to calibrate the meter before each test. The meter must be able to detect turbidity from 0 to 40 NTUs. Appendix B provides a sample specification for an acceptable turbidimeter. Table 4 lists some vendors of turbidimetric equipment.

Reference standard solutions can be obtained from the following sources:

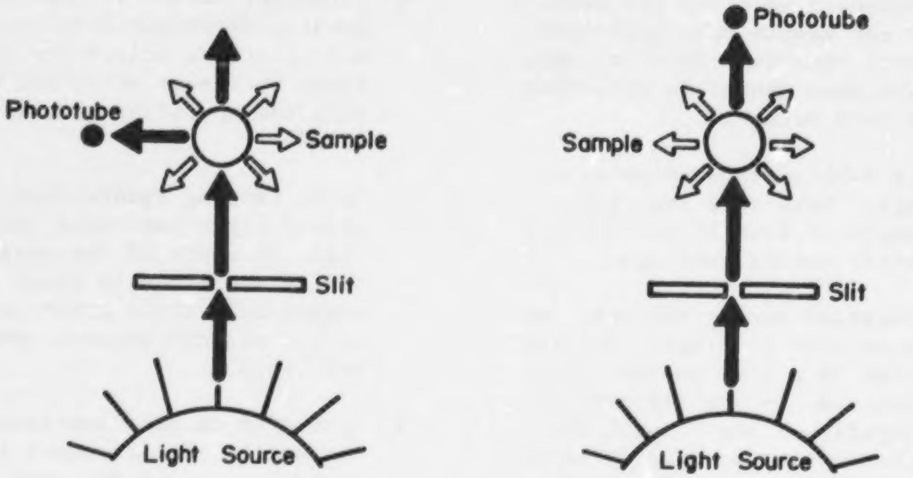
- Laboratory equipment suppliers
- Local state certified laboratories
- Preparation in your laboratory

You should ask the turbidimeter supplier for a list of certified standard suppliers. Alternatively, you may be able to have a local, state certified laboratory prepare reference standards at reasonable cost. Note that standard solutions must be replaced periodically. Try to locate a reliable supplier as nearby as possible. Perhaps a large water utility in your area could be used as a supplier since they may be preparing standard solutions for their own use.

Preparation of reference standards requires precision equipment and trained personnel. You should not prepare them in-house unless you are equipped to do so. Refer to Standard Methods[3] and References 5 and 6 for the procedures and equipment used to prepare reference standards.

Potential Interferences[5]

- Floating debris and rapidly settling particles can cause low readings. Retake those samples where debris (large particles) is present.
- Dirty, scratched or etched tubes cause high readings. Replace these immediately. **Do not touch the body of the tube where the light passes through.**



NEPHELOMETRIC TURBIDIMETER

CONVENTIONAL TURBIDIMETER

Figure 7. Comparison of Nephelometric and Jackson Candle Turbidity Measurement[5]

Table 4. Partial List of Nephelometric Turbidity Meter Suppliers[7,9]

Bristol Babcock Division Acco Industries, Inc.	40 Bristol Street Waterbury CT 06708
Fisher Scientific Company	711 Forbes Street. Pittsburgh, PA 15219
Hach Company	Box 389, Loveland, CO 80537
Roberts Filter Manufacturing Co.	6th & Columbia Avenue Darby, PA 19023
Sherman Machine and Iron Works	26 E. Main Street Oklahoma City, OK 73104
Technicon Industrial Systems	511 Benedict Avenue, Tarrytown, NY 10591
The Turbitrol Company	415 E. Paces Ferry Road, Box 12047 Atlanta, GA 30355
Turner Designs	2247A Old Middlefield Way, Mountain View, CA 94043

- Condensed water on the exterior of the sample tube gives erroneous results. This is important when measuring turbidity of cold waters.
- Air bubbles cause high readings. Make sure that the sample is free of air bubbles before taking readings.
- Vibration during the test can cause high readings. Put the meter on a flat surface in an area that is not affected by vibration. Don't touch the meter or the surface it is on while the reading is being made.
- Different sample volumes may produce different results. Be sure that you follow the directions with your meter and use only the specified sample volume.
- Color causing agents that absorb light may cause low readings. Be aware of the possibility and visually check for sample coloration prior to test. Discard suspect samples and retest.
- Turbidity causing substances can settle if the sample is allowed to stand for even a short period. All samples should be shaken vigorously before testing.

III. MEASURES TO TAKE IF THE TURBIDITY IS EXCESSIVE

INTRODUCTION

If it is determined that the turbidity level is excessive, two general approaches to reduce the level should be evaluated:

- Nontreatment Alternatives
- Treatment Alternatives

Each is discussed in this section. Economic and engineering data which further aid in the analysis of treatment and non-treatment alternatives is given in Section IV.

NONTREATMENT ALTERNATIVES

Small water systems faced with upgrading or installation of new facilities needed to meet turbidity standards may find that the nontreatment approach is the most economical. The "manufacture" of safe potable drinking water is subject to economies of scale as most other manufacturing processes; that is, it is cheaper to process and sell it in larger quantities. Also, it is generally true that the closer that the original water quality is to the desired final water quality, the lower processing costs are.*

Before adding treatment equipment for turbidity control, evaluate the nontreatment alternatives.

For example:

- **Water source management.** Contaminants and turbidity enter surface waters as a result of overland flow and stream impoundment pollution. If water quality tests indicate substantial pollution, particularly from turbidity, color, and organic compounds, a watershed and reservoir study should be carried out. **Try to minimize water contaminants at the source to reduce the need for expensive treatment equipment and large quantities of chemicals:**
    - Seek to control sediment related turbidity by identifying erosion sources such as agricultural practices and land development. Require developers to provide runoff and sediment control when building on slopes. Use raw water reservoirs or holding ponds to presettle turbid waters.
    - Identify and control industrial effluents. Monitor suspended solids discharge from upstream water and wastewater plants. Control algal growth in reservoirs.
    - Protect the watershed and reservoir from trash and litter dumping, including refuse, leaves and tree trimmings and the like. If possible, limit public access to areas adjacent to reservoirs.
- **Water source substitution.** Required treatment and disinfection costs are directly related to raw water quality.

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* Exceptions occur when polymer or clay must be added to water to enable the removal of the turbidity-causing substances.

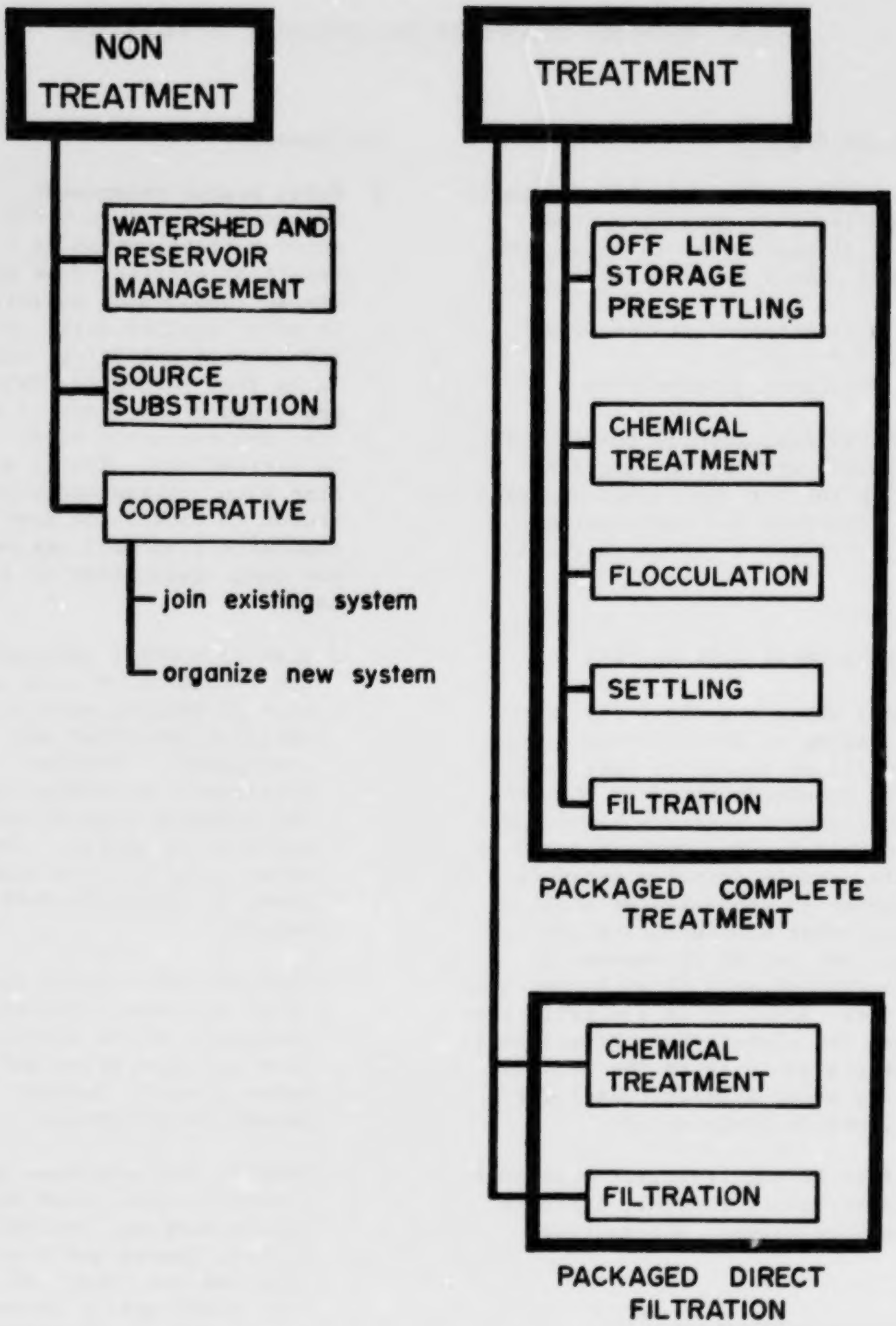

NON TREATMENT
WATERSHED AND RESERVOIR MANAGEMENT
SOURCE SUBSTITUTION
COOPERATIVE
join existing system
organize new system
TREATMENT
OFF LINE STORAGE PRESETTLING
CHEMICAL TREATMENT
FLOCCULATION
SETTLING
FILTRATION
PACKAGED COMPLETE TREATMENT
CHEMICAL TREATMENT
FILTRATION
PACKAGED DIRECT FILTRATION

Figure 8. Nontreatment and Treatment Alternatives for Meeting NIPDWR Turbidity Standards

Costs could be greatly reduced by switching from a turbid surface water source to a clear well water. Disinfection costs would probably be reduced as well.

- **Regional Systems.** Regional systems are becoming more attractive as the need to, and costs of, producing high quality drinking water increase. Larger systems can spread the costs of water quality monitoring and analysis, and of operation and maintenance, over a larger user base, lowering per capita costs. The analysis of nontreatment alternatives should look at regional alternatives: either connecting to an existing regional system, or the formation of a new regional utility by joining with other nearby systems which may be experiencing similar water quality problems.

  Several government agencies can provide support to small water systems interested in regionalization. The Farmers Home Administration (FmHA) has the most experience in dealing with regionalization attempts, having the largest federal grant-loan program for rural water projects. HUD, the Appalachian Regional Commission, the Economic Development Administration and the Coastal Plains Commission all have limited federal funds available for rural water projects, including regionalization efforts by small water systems.

Nontreatment alternatives which involve regional systems are discussed in detail in a companion document, available as follows:

> Regionalization Options for Small Water Systems, U.S. EPA Office of Drinking Water, 401 M Street, SW, Washington, DC 20460.

TREATMENT ALTERNATIVES FOR TURBIDITY REMOVAL

Removing turbidity will require physical treatment, chemical treatment, or a combination of the two. As a general rule, the higher the raw water turbidity, the more complicated and costly the treatment scheme required. Contaminants which color the water may be difficult to remove but can be reduced by some of the treatment techniques used to reduce turbidity.

Figure 9 depicts the treatment processes that are discussed in this section. Each process discussed below is a separate and discrete treatment step, but all are interrelated and must be considered as part of an overall process scheme. Traditionally, water treatment plants have been constructed as a series of separate processes. Small utilities, however, can purchase **packaged** treatment systems which incorporate all of the processes within a very compact housing. Design of these treatment systems are discussed in detail in Section IV:

- Direct Filtration
- Direct Coagulation and Filtration
- Packaged Complete Treatment Systems

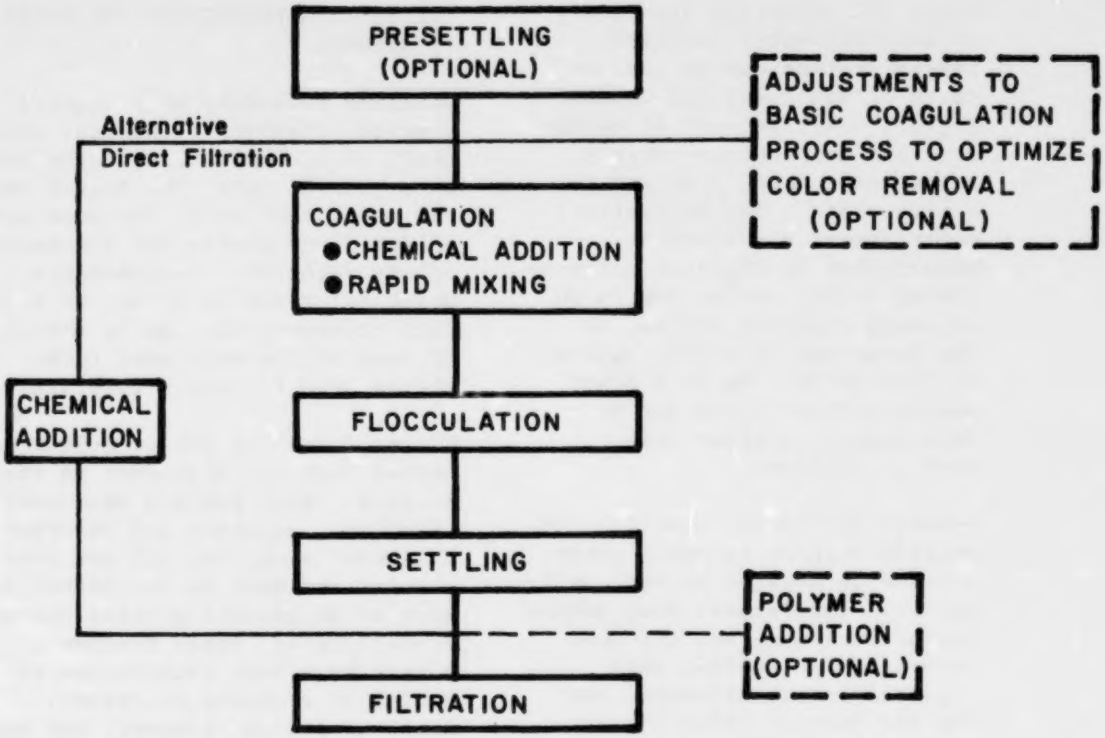

PRESETTLING (OPTIONAL)
Alternative Direct Filtration
ADJUSTMENTS TO BASIC COAGULATION PROCESS TO OPTIMIZE COLOR REMOVAL (OPTIONAL)
COAGULATION
●CHEMICAL ADDITION
●RAPID MIXING
CHEMICAL ADDITION
FLOCCULATION
SETTLING
POLYMER ADDITION (OPTIONAL)
FILTRATION

Figure 9. Turbidity Removal from Drinking Water

PRESETTLING

If your system uses surface water of highly variable quality, but has no raw water reservoir, use of a holding pond of 1 to 3 days detention should be evaluated. The holding pond provides **presettling** of the raw water allowing silt and sand to settle out. It also **equalizes** the flow to the water treatment plant by averaging out short term changes in raw water quality. Equalization makes plant operation simpler by reducing the need to adjust treatment chemical dosages. Also, if not removed, abrasive grit and other solids may shorten the life of pumps and other mechanical parts of the treatment plant.

Certain raw water supplies may support rapid growth of nuisance aquatic organisms, such as algae, when held in equalization ponds. Before opting for the use of ponds, investigate this possibility during the initial stage of plant design. In some cases, algae growth can be controlled through the application of copper sulfate ($CuSO_4$).

COAGULATION

Coagulation is a process that aids in the aggregation of small, hard to settle, particles into larger ones that can be removed by gravity (sedimentation) and/or by filtration. **Coagulating chemicals** are added to a turbid water, creating conditions that allow the formation of **floc**, or groupings of particles. As seen in Figure 10, coagulation is the first step in the solids (turbidity) removal process.

Chemical coagulants initiate particle aggregation by three main mechanisms: electrical charge reduction, interparticle bridging, and enmeshment. These are illustrated in Figure 11. Flocculation, discussed later herein, continues the process of particle aggregation.

Coagulating Chemicals

The chemicals most commonly used for coagulating solids in potable water treatment are listed in Table 5 along with their chemical formulas and typical dosage ranges. Dosage for a specific water must be determined by actual testing of the raw water. Coagulant combinations may be used to reduce overall chemical costs. For example, it is becoming quite common to combine a traditional coagulant such as alum with organic polymers to reduce overall chemical consumption, sludge production and costs.

Jar tests are the simplest procedure for selecting optimal chemical type and dosage. Figure 12 is a photograph of a typical jar test apparatus. Appendix C details the procedure for conducting jar tests. Basically, the test is simple. Varying amounts of a coagulant are added to samples of the raw water in each of six stirred beakers and the results are observed. Initial mixing is rapid, followed by gentle mixing. The test is repeated for the full range of practical dosages and for various coagulants. The coagulant and dosage which flocculates the raw water most effectively is used to approximate coagulant needs for the full scale installation. Jar tests can be conducted by many laboratories, colleges and universities, and some consulting engineers. Most chemical vendors will also assist you in determining optimum chemicals and dosages. Some chemical suppliers are listed in Table 6.

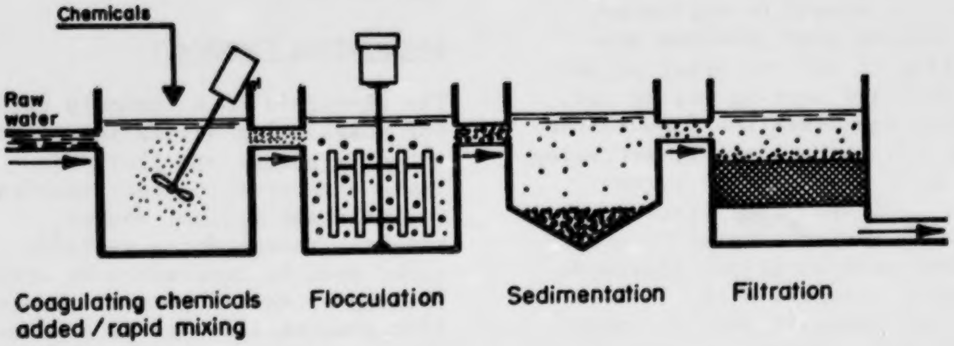
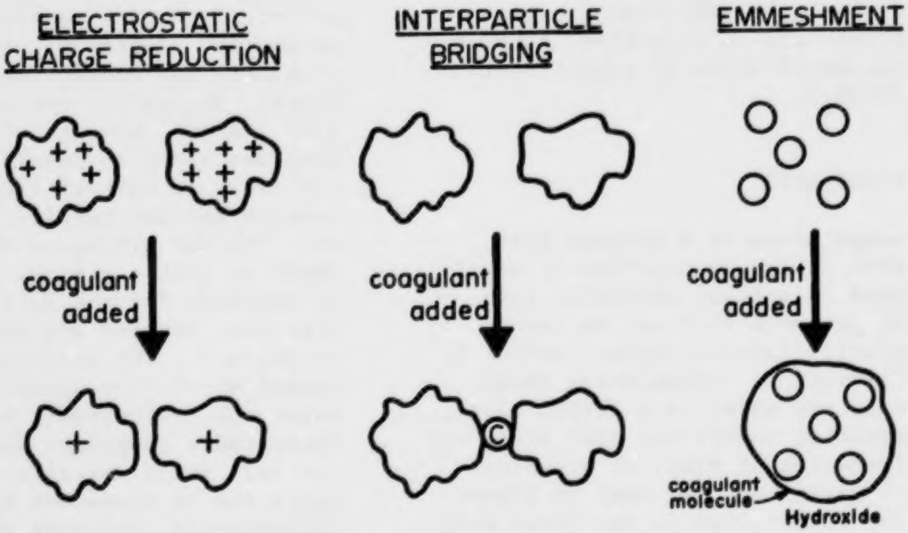

Chemicals
Raw water
Coagulating chemicals added / rapid mixing
Flocculation
Sedimentation
Filtration

Figure 10. Coagulation/Flocculation/Sedimentation/Filtration


ELECTROSTATIC CHARGE REDUCTION
INTERPARTICLE BRIDGING
EMMESHMENT
coagulant added
coagulant added
coagulant added
C
coagulant molecule
Hydroxide

The larger particles thus formed can be settled by gravity or filtering.

Figure 11. Mechanisms of Chemical Coagulation

Table 5
Commonly Used Coagulating Agents

Name	Chemical Reaction	Dosage Range
Aluminum Sulfate	$Al2(SO4)_3 + 3Ca(HCO_3)_2 = 3CaSO_4 + 2Al(OH)_3 + 6CO_2$	15 to 100 mg/l of $Al_2(SO_4)_3$, 18 H_2O (commercial) according to the turbidity of the water.
Sodium Aluminate Alone	$NaAlO_2 + Ca(HCO_3)_2 + H_2O = Al(OH)_3 + CaCO_3 + NaHCO_3$	5 to 50 mg/l of Al_2O_3 (commercial) according to the turbidity of the water.
Aluminum Sulphate-Sodium Aluminate	$6AnAlO_2 + Al_2(SO)_4)_3, 18H_2O = 8Al(OH)_3 + 3Na_2SO_4 + 6H_2O$	The weight of commercial sodium aluminate required is 75% of the weight of aluminum sulphate (commercial) for an equimolecular reaction. The dose of sodium aluminate may, however, be much less, in which case the reagent serves only to initiate the coagulation of the aluminum sulphate.
Sodium Aluminate + Ferric Chloride	$3NaAlO_2 + FeCl_3, 6H_2 = 3Al(OH)_3 + Fe(OH)_3 + 3NaCl$	Approximately equal weights of commercial sodium aluminate (50% Al_2O_3 and $FeCl_3$. $6H_2$ (commercial)
Ferric Chloride Alone	$2FeCl_3 + 3Ca(HCO)_3)_2 = 3CaCl_2 + 2Fe(OH)_3 + 6CO_2$	5 to 100 mg/l $FeCl_3$, $6H_2$ (commercial) according to the turbidity of the water.
Aluminum Sulphate + Hydrated Lime	$Al_2(SO_4)_3 + 3Ca(OH)_2 = 3CaSO_4 + 2Al(OH)_3$	One part of $Ca(OH)_2$ (lime) to three parts of $Al_2(SO_4)_3$, $18H_2$ (commercial). Lime is added to counteract the acidity of alum.

(Continued)

Table 5
Continued

Name	Chemical Reaction	Dosage
Aluminum Sulphate + Caustic Soda	$Al_2(SO_4)_3 + 6NaOH =$ $2Al(OH)_3 + 3Na_2SO_4$	The requirement of NaOH (caustic soda) is 36% of the dose of $Al_2(SO_4)_3$ $18\ H_2$ (commercial).
Aluminum Sulfate + Sodium Carbonate	$Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O =$ $2Al(OH)_3 + 3Na_2SO_4 + 3CO_2$ $Al_2(SO_4)_3 + 6Na_2CO_3 + 6H_2O =$ $2Al(OH)_3 + 3Na_2SO_4 + 6NaHCO_3$	One part of anhydrous sodium carbonate to 1 or 2 parts of $Al_2(SO_4)_3 \cdot 18H_2O$ (commercial).
Ferric Sulphate:	$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 =$ $2Fe(OH)_3 + 3CaSO_4 + 6CO_2$	10 to 50 mg/l of $Fe_2(SO_4)_3$, $9H_2O$ (commercial) according to the turbidity of the water.
Ferric Sulphate + Hydrated Lime	$Fe_2(SO_4)_3 + 3Ca(OH)_2 =$ $2Fe(OH)_3 + 3CaSO_4$	The requirement of hydrated lime as $Ca(OH)_2$ is 40% of the quantity of iron sulphate $Fe_2(SO_4)_3$, $9H_2O$.
Ferrous Sulphate	$FeSO_4 + Ca(HCO_3)_2 =$ $Fe(OH)_2 + CaSO_4 + 2CO_2$	5 to 25 mg/l of $FeSO_4$, $7H_2O$ (commercial) according to the turbidity of the water. In aerated waters, the ferrous hydroxide oxidizes and becomes ferric hydroxide: $2Fe(OH)_2 + O + H_2O = 2Fe(OH)_3$
Ferrous Sulphate + Hydrated Lime	$FeSO_4 + Ca(OH)_2 =$ $Fe(OH)_2 + CaSO_4$	The requirement of $Ca(OH)_2$ (hydrated lime is 26% of the quantity of $FeSO_4 \cdot\ 7H_2O$.

(Continued)

Table 5
Continued

Name	Chemical Reaction	Dosage
Ferrous Sulphate + Chlorine	$2FeSO_4 + 3Ca(HCO_3)_2 + Cl_2 =$ $2Fe(OH)_3 + 2CaSO_4 + CaCl_2 + 6CO_2$	The requirement of chlorine is 12% of the quantity of $FeSO_4 \cdot 7H_2O$.
Sodium Aluminate + Magnesium Chloride	$2AlNaO_2 + MgCl_2 + 4H_2O =$ $2Al(OH)_3 + Mg(OH)_2 + 2NaCl$	The requirement of $MgCl_2 \cdot 6H_2$ is 125% of the weight of commercial sodium aluminate (with 50% Al_2O_3).
Ozone	Ozone is not a true coagulant as it has no action on the electric charges of the colloids in the water. However, in specific cases when water contains complexes linking organic matter to iron or manganeses, ozone can initiate a coagulation process. The complexes are destroyed by the ozone and the metal ions thus released are oxidized. With the necessary pH conditions, this may result in the formation of a small amount of a generally fragile precipitate. The density and cohesion properties of the floc so formed are inadequate to provide acceptable clarification, but may serve for filter coagulation.	

Table 6. Partial List of Coagulant Suppliers[7,8,9]

Name	Address*
Allied Chemical, Industrial Chemicals Division	Box 1139R, Morristown, NJ 07960
Allied Colloids, Inc.	161 Dwight Place, Fairfield, NJ 07006
American Colloid, Inc.	5100 Suffield Ct., Skokie, IL 60076
American Cyanamid	Wayne, NJ 07470
Calgon Corporation	Box 1346, Pittsburgh, PA 15230
Carus Chemical Co.	1500 8th. St., LaSalle, IL 61301
Diamond Shamrock Corp.	351 Phelps Ct., Irving, TX 75062
Dow Chemical, USA	2020 Dow Center, Midland, MI 48640
Dupont Chemicals Chemicals & Pigment Dept.	Wilmington, DE 19898
Hercules, Inc.	910 Market St., Wilmington, DE 19899
Jones Chemical Corp.	100 Sunny Sol Blvd., Caledonia, NY 14423
Leopold Company	227 S. Division St., Zelienople, PA 16063
Nalco Chemical	2901 Butterfield Rd., Oak Brook, IL 60521
Olin Corporation	Chemicals Group, 120 Long Ridge Rd., Stamford CT 06904
Permutit Co.	E. 49 Midland Ave., Paramus, NJ 07652
Petrolite Corp. Tretolite Division	369 Marshall Ave., St. Louis, MO 63119
Rohm & Haas Co.	Independence Mall W., Philadelphia, PA 19105
Stauffer Chemical Co.	New York, NY

* National headquarters. Many of these vendors have regional branch offices or local representatives.

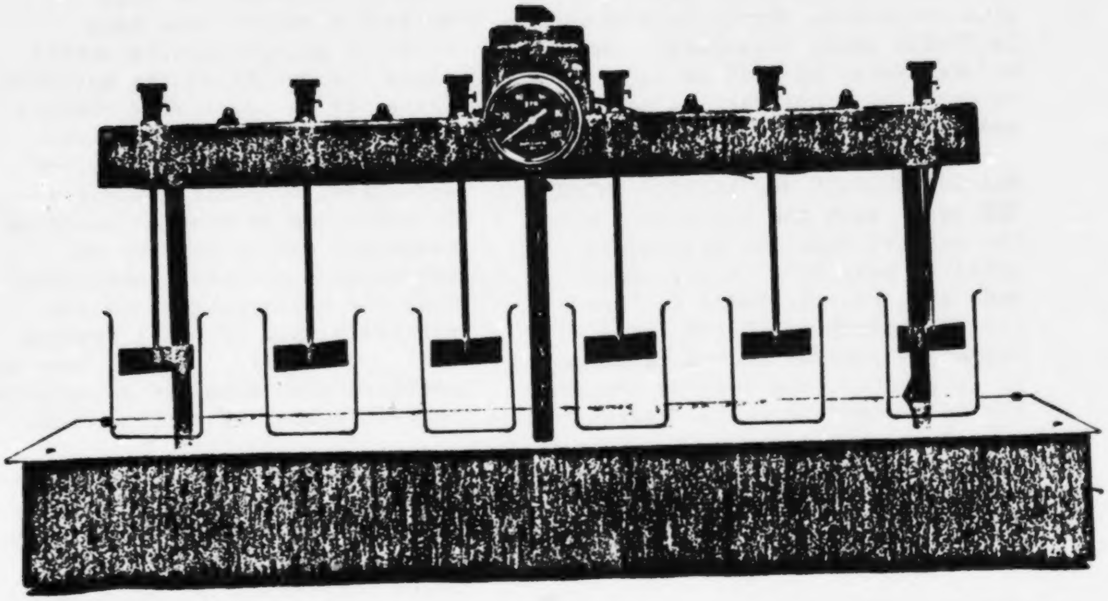


Figure 12. Jar Test Apparatus

Characteristic Chemistry of the Common Coagulants

ALUM, an acidic compound, reacts with the alkalinity (carbonate and bicarbonate) of natural waters to form aluminum hydroxide, a fluffy white flocculating agent. Mixing alum in water causes it to break down as shown by the equations below:

$$\underset{\text{alum}}{Al_2(SO_4)_3} \longrightarrow 2Al^{+++} + 3SO_4^{=}$$

It then combines with ionized water,

$$\underset{\text{water}}{6H_2O} \longrightarrow \underset{\text{hydrogen}}{6H^+} + \underset{\text{hydroxide}}{6OH^-}$$

To form aluminum hydroxide, a fluffy white coagulant:

$$\underset{\text{aluminum ion}}{2Al^{+++}} + \underset{\text{hydroxyl ion}}{6OH^-} \longrightarrow \underset{\text{aluminum hydroxide}}{2Al(OH)_3}$$

In the process, hydrogen (H^+) ion is liberated, making the water more acid. Unless lower pH (more acidic condition) is required, lime ($Ca(OH)_2$), soda ash (Na_2CO_3), or caustic soda ($NaOH$) may be needed to be added to keep the pH in the optimum range for effective coagulation. Also, for each milligram per liter (mg/l) of alum added, the sulfate content of the water increases 0.5 mg/l. This may be important if raw water sulfate is high or if the plant uses ion exchange for nitrate removal.

FERRIC SULFATE and FERRIC CHLORIDE react in a similar manner as alum to produce ferric hydroxide (a fluffy white coagulant). As before, water pH will be reduced unless lime, soda ash, or caustic soda are added.

FERROUS SULFATE and FERROUS CHLORIDE react with the alkalinity of the natural water or with added alkaline materials (e.g., lime, soda ash, caustic soda) to form ferrous hydroxide ($Fe(OH)_2$). If oxygen is present in the water or it is aerated, the ferrous hydroxide is changed to ferric hydroxide. Ferrous hydroxide is slightly soluble in water and thus may cause high iron content of the treated water, causing stains on consumers' plumbing fixtures.

SODIUM ALUMINATE ($NaAlO_2$) is an alkaline coagulant that can be effective in relatively small doses. It is expensive compared to other chemicals and therefore may be used in conjunction with less expensive coagulants such as alum. Sodium aluminate is not effective if the raw water is very soft. When mixed with water, aluminum hydroxide is formed as the final coagulating agent.

LIME ($Ca(OH)_2$) can be used for coagulation as well as for pH adjustment. Relative to other coagulants, large quantities of lime may be required for turbidity removal, producing substantial waste sludge which must be disposed. Lime treated waters, if not properly stabilized, tend to deposit calcium carbonate ($CaCO_3$) scale in consumers' plumbing, particularly hot water heaters.

POLY-ELECTROLYTES (polymers) have synthetic or natural long chain organic compounds of high molecular weight that have function groups (active sites) along the length of the molecule. These may be negatively charged (anionic polymers), positively charged (cationic polymers) or uncharged (nonionic polymers). Polymers can be used alone or as a **coagulant aid** to improve the performance of other chemicals. They are quite costly and are generally used in small dosages (0.1 - 0.5 mg/l). Often, they are combined with alum and dosed prior to filtration, as a **filter aid.**

COAGULANT AIDS include polyelectrolytes, clays (such as bentonite) and activated silica. They are added in conjunction with other coagulants and serve to enhance coagulation and minimize chemical addition.

Chemical Feeding and Mixing

Coagulant chemicals are purchased either in dry or liquid form, in bulk, bag, or drums (for liquid). Dry chemicals require fairly elaborate dissolving and feeding equipment. Liquid feed systems are somewhat simpler but their chemicals are often more costly.

For effective chemical usage, mixing with the process water stream must be **rapid** and **complete.** A high speed mixer, shown in Figure 14, is often used. Detention time (the time each unit volume of water spends in the mixing chamber) is typically 10 to 30 seconds. In-line mixers, blenders and mixing pumps are also used for rapid mixing (Figure 14).

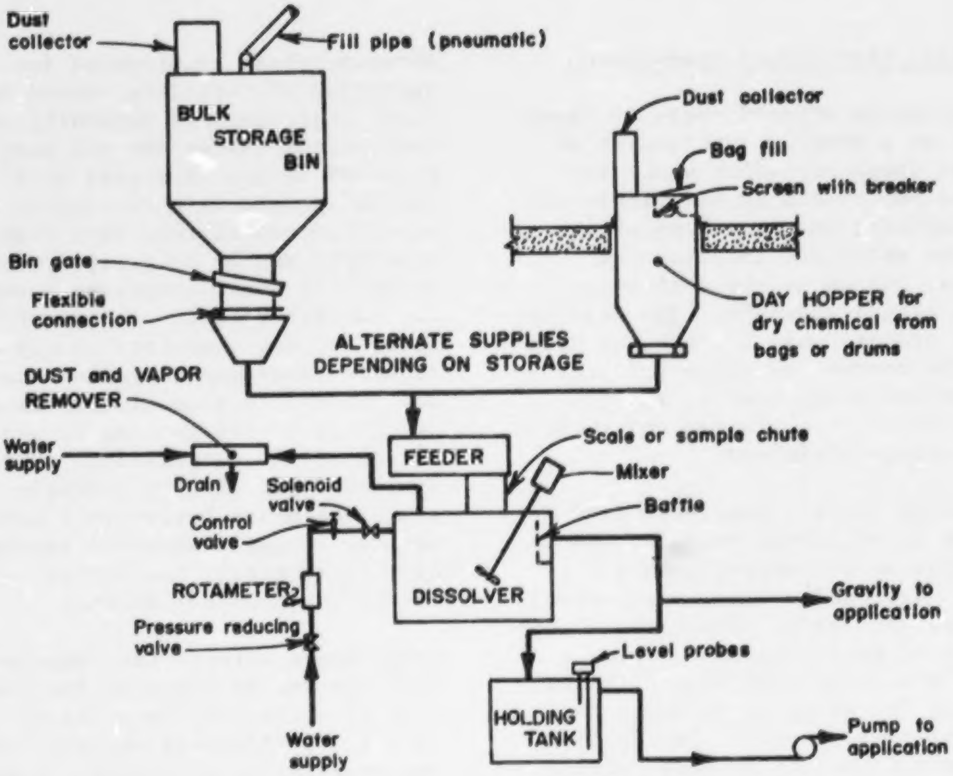

Dust collector
Fill pipe (pneumatic)
BULK STORAGE BIN
Dust collector
Bag fill
Screen with breaker
Bin gate
Flexible connection
DAY HOPPER for dry chemical from bags or drums
ALTERNATE SUPPLIES DEPENDING ON STORAGE
DUST and VAPOR REMOVER
Water supply
FEEDER
Scale or sample chute
Mixer
Drain
Solenoid valve
Control valve
Baffle
ROTAMETER
DISSOLVER
Gravity to application
Pressure reducing valve
Level probes
HOLDING TANK
Water supply
Pump to application

Figure 13. Chemical Dissolving and Feeding Equipment

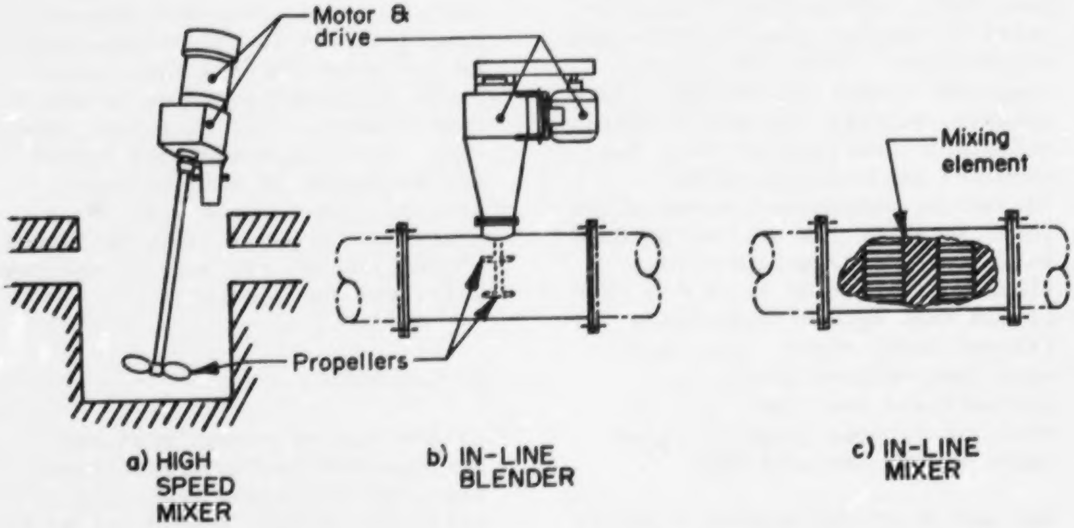

Motor & drive
Mixing element
Propellers
a) HIGH SPEED MIXER
b) IN-LINE BLENDER
c) IN-LINE MIXER

Figure 14. Some Rapid Chemical Mixers

Factors that Affect Coagulation

Coagulation effectiveness is dependent on a complex interaction of water characteristics which include pH, turbidity (magnitude and variation), chemical composition of the water and temperature. Of these, the pH is the most important single variable. The coagulation process must be operated within the correct pH range for the coagulant being used if the process is to be optimized and chemical dosage minimized.

Aluminum salts (alum) have been shown to work best when applied to a water of pH ranging from 6.0 to 7.8. Iron salts (ferric chloride) behave similarly, though[10] the acceptable range is broader. It may be necessary to adjust the pH of the raw water to optimize the coagulation process. Jar testing, discussed earlier in this section, is used to find optimal coagulation conditions.

Natural waters nearly always contain inorganic salts (sulfates, phosphates, carbonates, bicarbonates) of varying concentration and composition. These can affect coagulant choice and dosage. For example, sulfate ion concentration affects the optimal pH range for chemical application, while increasing phosphate concentration tends to shift the optimum pH downward toward more acidic conditions. It has been generally concluded that **anions** (negatively charged ions) affect coagulation more than **cations** (positively charged) and that they tend to move the optimum coagulation[10] pH range toward the acid side.

The nature of the suspended solids turbidity) being coagulated also affects coagulant selection and dosage. In general, there is a minimum dosage requirement for coagulation of turbidity caused by clay, regardless of turbidity concentration. Above the minimum, required dosage increases at a declining rate with increasing turbidity concentration. Very high turbidity may be coagulated with relatively small coagulant dosages due to this effect. Waters of low turbidity may coagulate poorly and require excessive coagulant dosage. Particle size distribution of the turbidity causing substances can affect coagulation. Wider distributions of clay particle sizes coagulate better than narrow ranges. Organic material carried by clay seemingly has little effect on coagulant demand.

Temperature affects the coagulation process by changing the viscosity of water and, to a lesser extent, by affecting the rate of the coagulation reactions. Very low temperature waters may exhibit lower optimum pH levels, with the effect more pronounced as[10] coagulant dosage is decreased.

Choice of coagulant and optional coagulant aid is, of course, one of the prime factors that influences coagulation. Alum is the most commonly used coagulant; however, iron salts may work better for treatment of soft colored waters. The coagulant(s) for a given system should only be chosen after thorough analysis of the raw water and jar testing.

FLOCCULATION

Solids that are coagulated and precipitated in the coagulation/rapid mix treatment stage are still too finely divided for effective removal. The **flocculation** process aids in the formation of large settlable and filterable solids by creating a suitable environment for agglomeration of the small solids. In the flocculator, very small (colloidal) solids collide with each other and agglomerate into larger solids or **floc.**

The flocculation process is carried out in a basin which provides 15 to 30 minutes detention time while some type of mixer provides slow, gentle stirring. Figure 15 depicts two common flocculator types; other types include static baffle, and diffused aeration flocculators. Flocculation is basically a controlled mixing process and is therefore quite dependent on control of velocity, detention time and short circuiting. Agitation in the flocculator must be sufficiently intense for solids contact and compaction, but below the level at which a substantial number of floc would be broken down. Of course, successful flocculation is also very much influenced by raw water characteristics and proper application and control of coagulant.

SEDIMENTATION

The sedimentation process separates the solids containing floc from the clear water by providing a stilling basin with carefully controlled fluid flow and a means of settled solids removal. The flocculated solids are heavier than water, hence they sink to the floor of the unit where they are removed. Figure 16 illustrates some typical clarifier configurations used for sedimentation in water treatment plants.

Clarifiers are usually designed on the basis of surface loading (gpd/sq.ft. or lpd/sq.m. surface area) and detention time (hours). Rise rate, in feet or meters per hour, may be specified as an alternative to surface loading. Surface loading (SL) is related to rise rate (RR) as follows:

English Units:

$$\text{RR(ft/m)} = \frac{\text{SL (gpd/sq.ft.)}}{179.5}$$

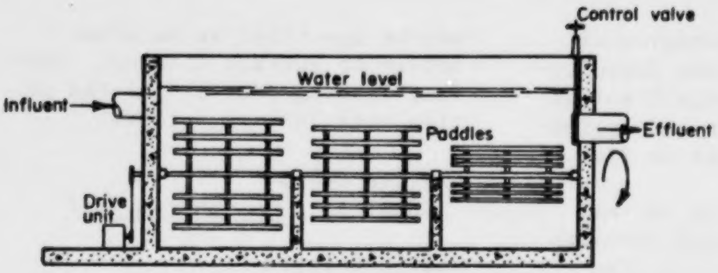
Metric Units:

$$\text{RR(m/m)} = \frac{\text{SL (lpd/sq.m.)}}{1000}$$

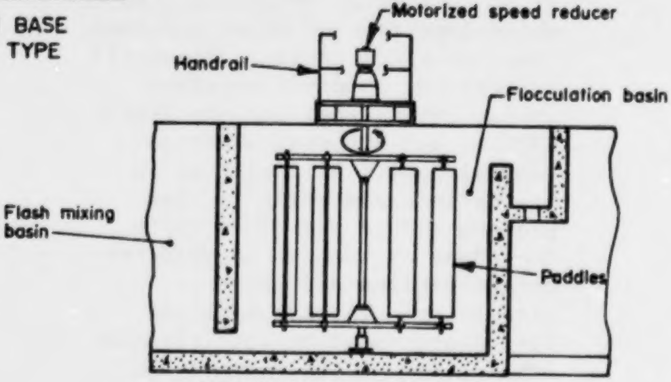
Typical water treatment clarifier detention time is 2 to 4 hours with an overflow rate of 350 to 550 gpd/sq.ft.[11,12] (14,260 - 22,407 lpd/sq.m.)

Clarifiers are also described by the method used for settled solids (sludge) removal. **Scraper** clarifiers use wiper blades that move slowly along the floor, pushing the sludge to an opening in the center (circulator clarifiers) or at one end (rectangular clarifiers) where it is pumped away by solids handling pumps. **Suction lift** clarifiers have hydraulic vacuum heads which move slowly over the clarifier floor, lifting the solids out. Some clarifiers have no scraping on vacuuming equipment. Rather, they use **hopper bottoms;** steeply sloped floors formed into an inverted cone or pyramid. Solids fall by gravity to the removal pipe at the bottom. This approach is more often used in small clarifiers to simplify operation and lower costs.

Upflow solids contact clarifiers combine the mixing, coagulation, flocculation and settling functions into one compact unit (Figure 17). By flowing the flocculated influent through the settled solids layer, enhanced solids removal is obtained at higher flow rates. The process works by matching the settling

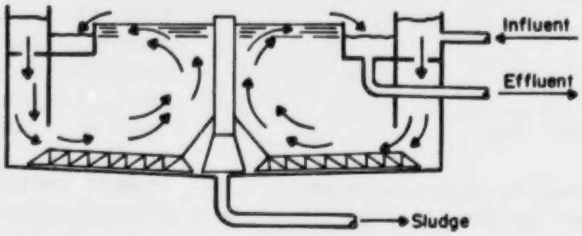

Control valve
Water level
Influent
Paddles
Effluent
Drive unit

MECHANICAL FLOCCULATION BASE
HORIZONTAL SHAFT-REEL TYPE

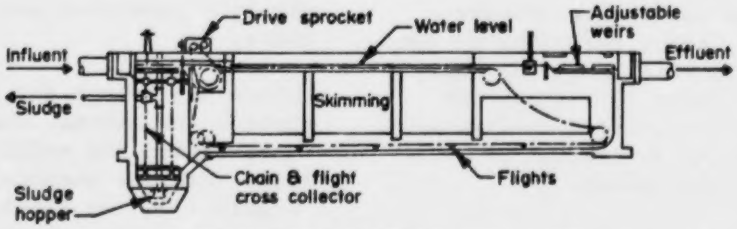

Motorized speed reducer
Handrail
Flocculation basin
Flash mixing basin
Paddles

MECHANICAL FLOCCULATOR
VERTICAL SHAFT PADDLE TYPE

Figure 15. Flocculators


Influent
Effluent
Sludge

CIRCULAR RIM-FEED, RIM TAKE-OFF CLARIFIER


Drive sprocket
Water level
Adjustable weirs
Influent
Effluent
Sludge
Skimming
Sludge hopper
Chain & flight cross collector
Flights

RECTANGULAR CLARIFIER WITH CHAIN
AND FLIGHT COLLECTOR

Figure 16. Clarifiers

velocity of the floc to the upward velocity of the water, causing the formation of a sludge "blanket" which enhances solids capture. As might be expected, operation of solids contact clarifiers requires good control of flow and coagulation. Upflow clarifiers are widely used in water softening processes and are generally applied in larger water treatment plants.

The time required for suspended solids to settle from the water surface to the floor of the clarifier is largely a function of particle size and weight and the quiesence (stillness) of the liquid mass. Theoretically, clarifier size could be greatly reduced by decreasing the distance of fall of the solids particle. Also, it is quite difficult to eliminate stray currents and other hydraulic disturbances in large tanks of water. **Tube** and **plate** clarifiers (or standard clarifiers to which tubes and plates have been added) have hundreds of small settling cells in the clarifier liquid space, greatly enhancing performance per unit of surface area. Figure 18 depicts a tube clarifier frequently used in packaged water treatment systems. Each tube functions like a small clarifier, discharging settled solids downward and clear water at the top. Tubes can be retrofitted into existing poorly performing clarifiers as well. Other similar units may use hexagonal or square tubes, or stacks of shallow plates. Sedimentation is not used in direct filtration systems.

FILTRATION

Filters remove suspended solids by three principal mechanisms (Figure 19).

- Surface filtration - large solids settle out or are trapped at the surface of the filter bed.
- Physical straining - smaller solids cannot pass the gap between filter particles and are trapped.
- Adhesion - the smallest solids that can readily pass through the pores in the filter bed may be attracted by weak forces which cause them to adhere to the surface of individual filter particles.

Depending on the type of filter used (discussed below) and the solids being filtered, solids are entrapped on the surface of the filter as well as in the body of the bed. Filter types and designs are quite numerous. However, **granular media** and **diatomite** are the most common types used in water treatment.

Granular Media Filters

As typically applied to potable water treatment in the past, granular media filters are beds of select sand 1-1/2 to 3 feet deep through which the water is passed to physically remove solids.[12] In more recent years, there has been a proliferation of filtration devices and filter media as the nature of the physical and chemical processes used in filtration have become better understood.

The simplest filter has at least three main components.

- **A housing** to hold the filter bed and appurtenances.
- **A filter bed**, often consisting of fine filter sand on a gravel bed.

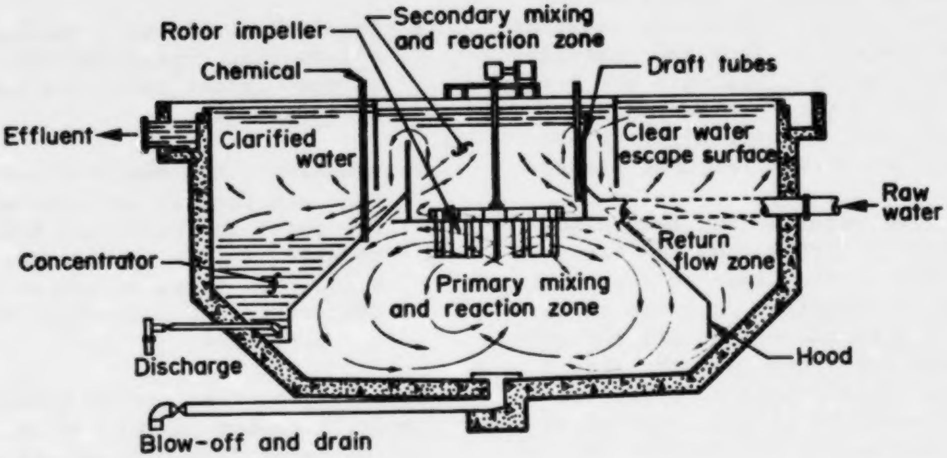

Rotor impeller
Secondary mixing and reaction zone
Chemical
Draft tubes
Effluent
Clarified water
Clear water escape surface
Raw water
Return flow zone
Concentrator
Primary mixing and reaction zone
Discharge
Hood
Blow-off and drain

Figure 17. Clarifier/Flocculator

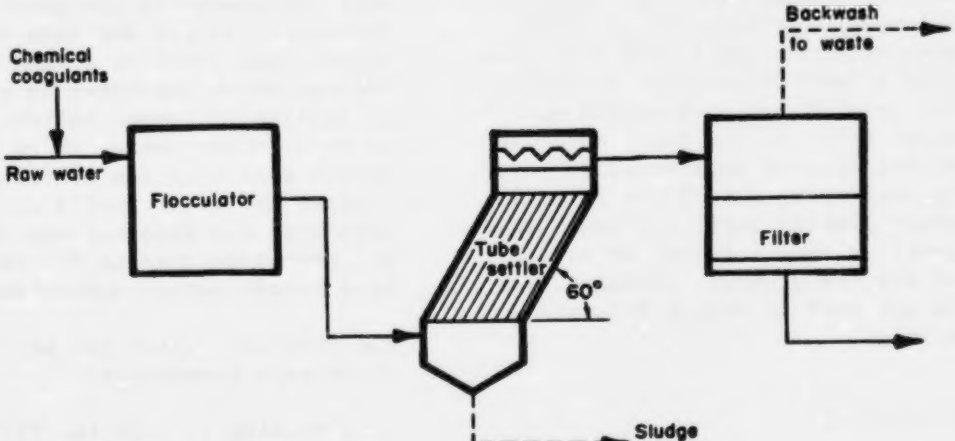
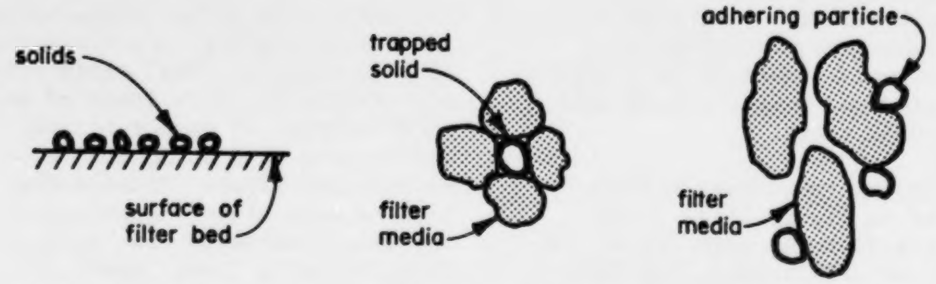

Chemical coagulants
Raw water
Flocculator
Tube settler
60°
Backwash to waste
Filter
Sludge drawoff

Figure 18. Tube Clarifier



a) Surface entrapment b) Physical straining c) Adhesion

Figure 19. Principal Mechanisms of Filtration

- **Underdrains** to collect and carryoff filtered waters.

A filter may also be equipped with backwashing equipment to allow for cleaning of the sand bed by reversing the flow through the unit, dislodging the trapped solids.

Three types of granular media filters are in common use today:

- Slow sand filters

- Rapid sand filters

- Multimedia filters

Slow sand filters. These filters are characterized by simple design and operation, and relatively low flow rates per unit of surface area. They are normally not equipped with backwashing equipment; rather cleaning is accomplished by removing and replacing the top several layers of sand when plugged. Slow sand filters can often be used on low turbidity waters with no chemical addition and flocculation. However, since most of the solids are trapped near the filter surface, this type of filter has relatively low solids capacity and is poorly suited for filtration of very turbid waters. They are appropriate for use where it is desirable to filter the water to ensure its microbiological quality even though the turbidity per se is not a problem.

Rapid sand filters. Rapid sand filters evolved from the need to increase filtration capacity and ease of cleaning in larger installations. Rapid filters operate at about 30 times the filtration rate of slow sand filters; hence they take up less space for equivalent flows.

However, rapid filters must be equipped with back washing equipment as they require more frequent cleaning as well. Although their operation is considerably more complex than slow filters, rapid filters can cope with a broader range of water quality and are best suited to filtration of waters which require chemical coagulation. Figure 20 is a typical rapid sand filter widely used in the U.S. today.

Conventional rapid sand filters depicted in Figure 21(a) often feature a 30 to 40 inch (76 to 101 cm) bed of sand graded from fine to coarse. Rapid filters are much like slow filters in that most of the solids are trapped at or near the surface, limiting bed capacity for solids. Several variations on this approach, developed to improve solids handling capacity and/or filter cleaning, are shown in Figures 21(b) and (c). Newer developments in improved filter media, discussed next, are rapidly displacing conventional rapid sand filtration for potable water filtration.

Multimedia Filters. Theoretically, the ideal filter would be evenly graded in particle size, coarse to fine, as shown in Figure 22. Such a filter would function as a progressive sieve, trapping the larger solids at the top and the smallest deep within the bed. This would maximize the solids holding capacity of the bed, substantially reducing backwash needs over filters that use only the top portion of the bed.

To more closely approximate the ideal filter, multi-media filters have been developed. Figures 21(d) and (e) illustrate two of the most common variations: the "dual media" and "mixed media" filters. Common to most of the variations on the conventional sand filter is better utilization of the filter bed by grading the media from coarse at the top to fine at the bottom.* This allows for particles to penetrate into the media body better distributing the solids loading over the volume of filter media. **Dual media** filters typically use a layer of anthracite coal 18 inches (46 cm) thick above an 8 to 10 inch (20 - 25 cm) sand layer. **Mixed media** filters more closely approximate the ideal coarse to fine gradation, by using three layers of media. The filter bed is 30 inches (76 cm) deep, consisting of 18 inches (46 cm) of anthracite coal on top, followed by 9 inches (23 cm) of silica sand with 3 inches (8 cm) of garnet sand on the bottom.

The media is graded in size so that backwashing (reversing flow) in the filter causes a fairly uniform gradation from coarse to fine in the media. Mixed media filtration is a patented process, available from Neptune Micro Floc Corporation, Corvallis, Oregon. Claimed advantages are longer filter runs between cleaning (backwashing), higher solids handling capability, and lower filtered water turbidity. Figure 23 is a cutaway drawing of mixed media filter suitable for a small water utility. Most new and retrofitted water filtration plants in the U.S. use multi media technology.

Granular media filters (rapid sand and multimedia) are available as either **gravity** filters

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* However, the bottom of the filter, including the underdrains includes a layer of gravel.

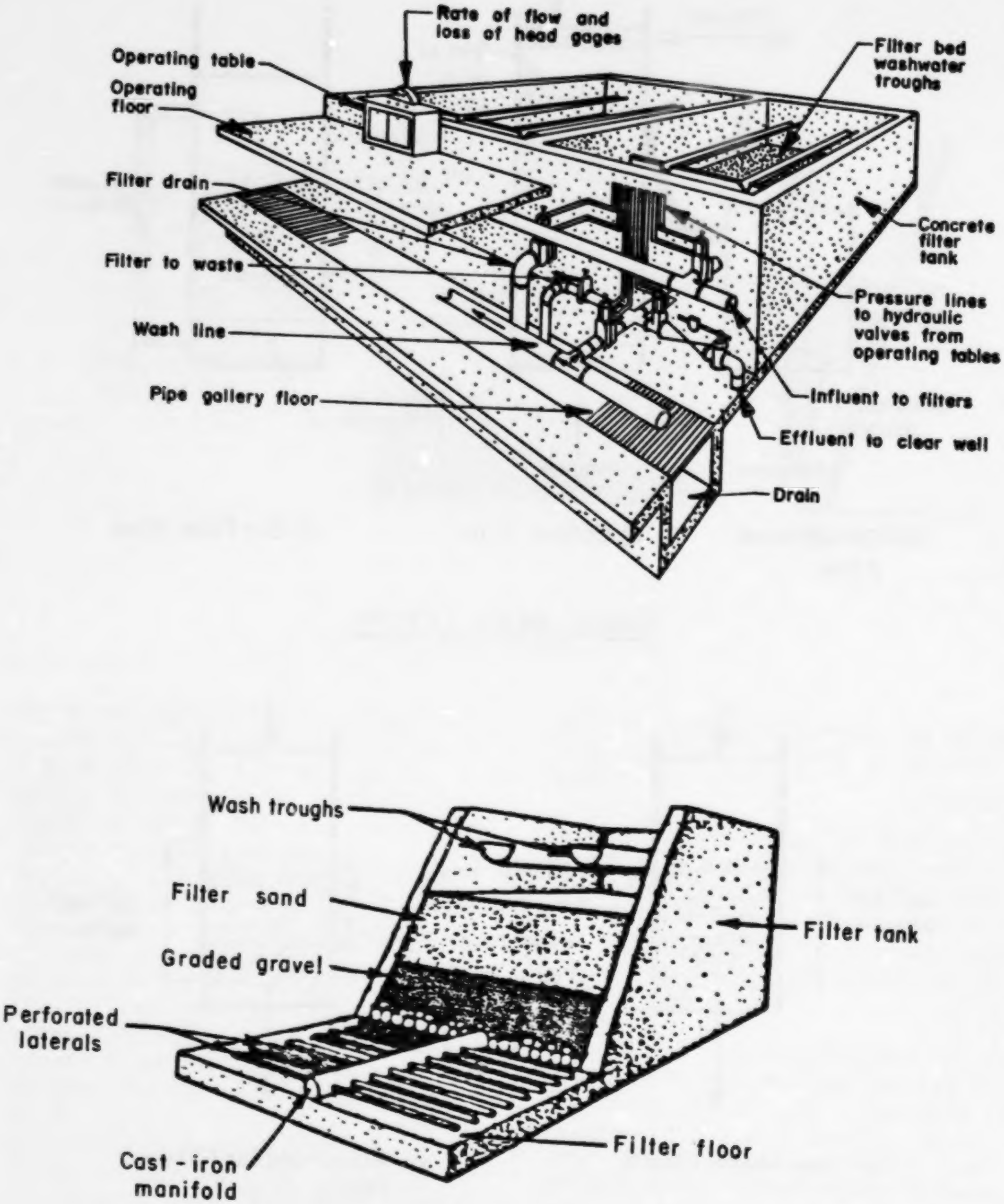
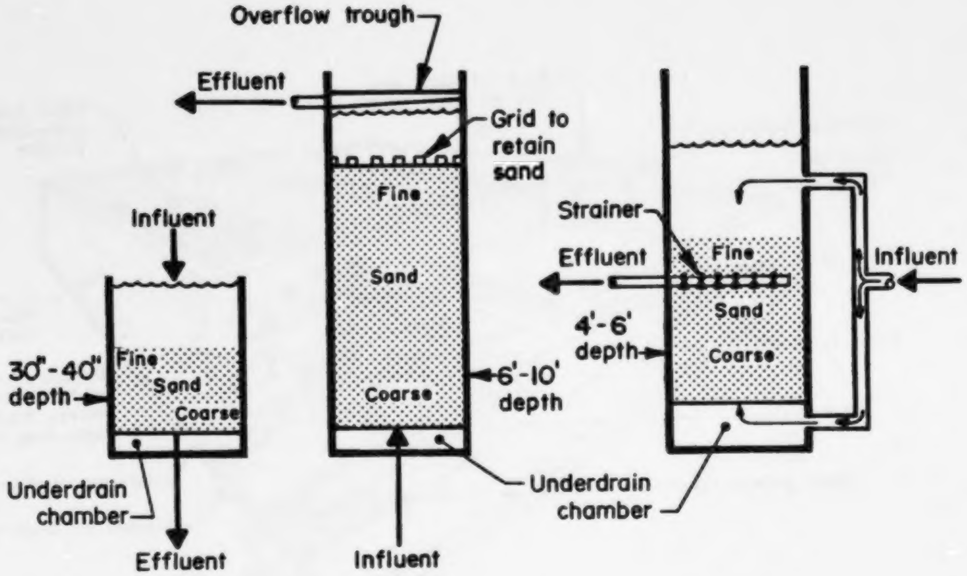

Rate of flow and loss of head gages
Operating table
Operating floor
Filter bed washwater troughs
Filter drain
Concrete filter tank
Filter to waste
Pressure lines to hydraulic valves from operating tables
Wash line
Influent to filters
Pipe gallery floor
Effluent to clear well
Drain
Wash troughs
Filter sand
Filter tank
Graded gravel
Perforated laterals
Filter floor
Cast - iron manifold

Figure 20. Typical Rapid Sand Filter[8]

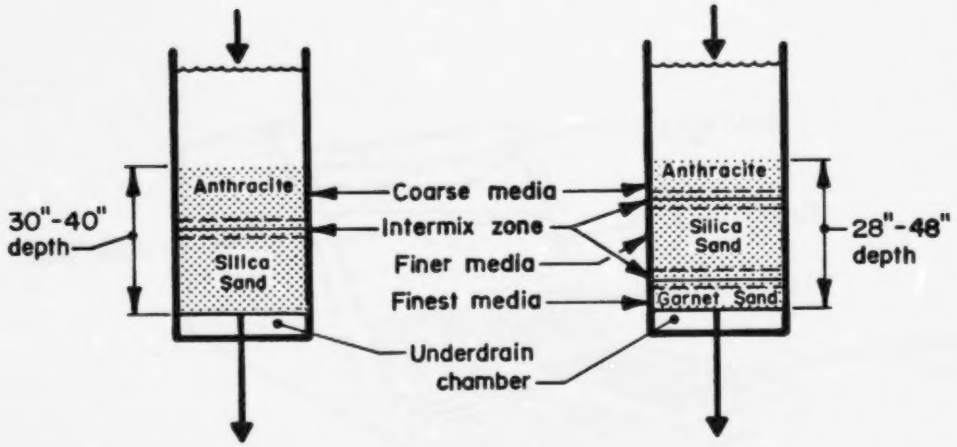

Overflow trough
Effluent
Grid to retain sand
Influent
Fine
Sand
Coarse
30"-40" depth
Underdrain chamber
Effluent
6'-10' depth
Influent
Underdrain chamber
Strainer
Effluent
Influent
4'-6' depth

a) Conventional Filter

b) Upflow Filter

c) Bi-Flow Flow

SINGLE MEDIA FILTERS


Anthracite
Silica Sand
30"-40" depth
Coarse media
Intermix zone
Finer media
Finest media
Underdrain chamber
Garnet Sand
28"-48" depth

d) Dual Media Filters

e) Mixed-Media Filters (Triple Media)

MULTI MEDIA FILTERS

Figure 21. Filter Configurations

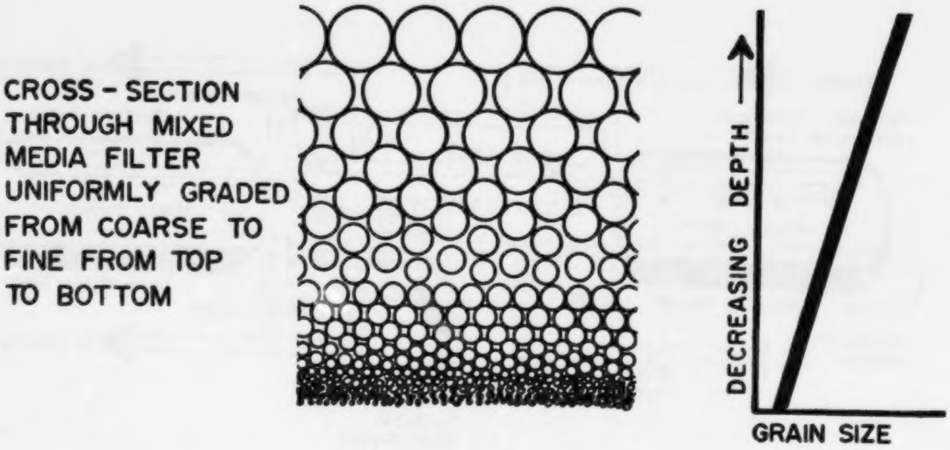

CROSS - SECTION THROUGH MIXED MEDIA FILTER UNIFORMLY GRADED FROM COARSE TO FINE FROM TOP TO BOTTOM
DECREASING DEPTH
GRAIN SIZE

Figure 22. Ideal Filter

or as pressure filters. Gravity filters are generally open on top (Figure 20) and rely on the weight of water above the bed to force the water through. As the filter becomes plugged, the height of water (head) above the filter increases. Generally, these filters are controlled by the head of water. When it reaches a predetermined level, the filter is taken out of service and cleaned by backwashing (reversing flow). Gravity filters are almost always used for turbidity removal in drinking water plants. Pressure filters such as the one shown in Figure 24 use an enclosed pressure tank, generally fabricated from steel. Water is pumped into the filter and forced through the bed under pump pressure. As the filter becomes clogged, the pumping pressure rises to a predetermined level, at which time backwash cleaning is initiated.

Pressure filters may be used for iron and manganese removal from well waters. Many states discourage or prohibit their use for turbidity removal unless they are preceded by coagulation, flocculation and sedimentation.

Rapid granular media filters (rapid sand and multimedia) are typically operated at flow rates ranging from 2 to 8 gpm/sq. ft. (815-326 lpm/sq.m.) of filter bed surface area. Mixed media filters tend to the upper end of this flow range, depending on influent water solids loading. Back washing may consume up to 10 percent of the filtered water supply, flowing at rates of 10 to 20 gpm/sq.ft. (407-815 lpm/sq.m.). To reduce

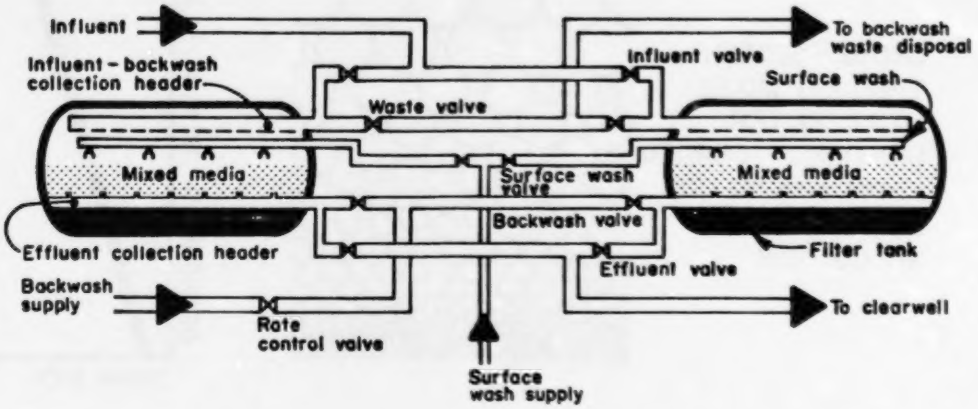

Influent
To backwash waste disposal
Influent - backwash collection header
Influent valve
Surface wash
Waste valve
Mixed media
Surface wash valve
Mixed media
Backwash valve
Effluent collection header
Filter tank
Effluent valve
Backwash supply
To clearwell
Rate control valve
Surface wash supply

Figure 23. Mixed Media Filter
Courtesy: Neptune Microfloc Corp.

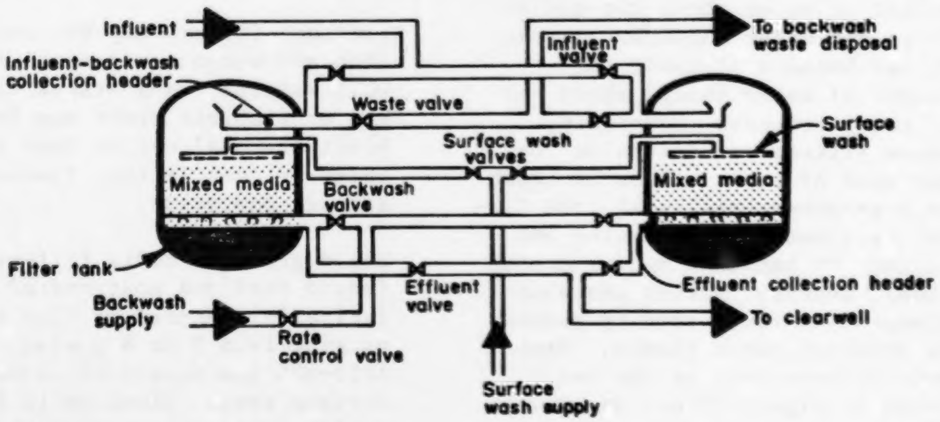

Influent
To backwash waste disposal
Influent valve
Influent-backwash collection header
Waste valve
Surface wash
Surface wash valves
Mixed media
Backwash valve
Mixed media
Filter tank
Effluent valve
Effluent collection header
Backwash supply
To clearwell
Rate control valve
Surface wash supply

Figure 24. Pressure Filter
Courtesy: Neptune Microfloc Corp.

backwash water consumption and improve filter cleaning, air may also be injected into the filter bed during backwash (air scrubbing). Surface accumulation of solids may be broken up and agitated by a rotary spray arm mounted above the surface (rotary spray washer). Slow sand filters do not use backwashing for cleaning.

Vendors of gravity and pressure filters are quite numerous and some are listed in Table 7.

Diatomite Filters

Diatomaceous earth filters, widely used for filtering swimming pool water, have been applied for drinking water treatment as well. In contrast with granular media filters, diatomite filters use a very thin layer of filter material (1/8 to 1/4 inch) (3.2-6.4 mm) which is coated out on a porous "septum" (Figure 25).[14] In use, additional diatomaceous earth is added to the influent water as "body feed." When the filter becomes plugged, it is backwashed and agitated to cause the diatomaceous earth to fall off the septum and be flushed from the filter tank. After fresh precoating, the unit is returned to service.

Cited advantages of diatomite filters include compact size, simplicity of operation (coagulating chemicals are not used) and excellent turbidity removal.

Three major factors affect diatomite filter operation:[11]

- Type and concentration of diatomite feed
- The filtration rate
- The pressure drop across the filter

Generally, filtration rates range from 1 to 2 gpm/sq.ft. (40.7-81.4 lpm/sq.m.) of septum area. Body feed and operating pressure (head) are estimated from solids loading and are a function of the type of diatomite and filter selected. A partial list of filter vendors is given in Table 8.

Diatomite filters are most suited for smaller water systems filtering water of low turbidity (less than 10TU)*. The principal advantages of diatomite in this application are low first cost and compact size. They are also quite widely used for emergency or seasonal water treatment systems.[11] Because the precoat and body coat will tend to slough off when filter flow is stopped, diatomite filters are operated on continuous flow basis. Typically, they are operated for a set period of time, usually 24 hours, discharging filtered water to storage, before shutdown/cleaning. The unit is precoated and returned to continuous service when stored water drops below the required minimum levels.

Diatomite filters are available as either pressure or vacuum filters, depending on whether the pressure pump is located upstream or downstream of the filters. Most diatomite filters are pressure units similar to the one shown in Figure 26.

PACKAGED TREATMENT SYSTEMS

The preceding discussion dealt with water treatment on a step by

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* Although there is no agreement on the upper limits of turbidity, most municipal experience falls in this range.[9]

Table 7
Partial List of Gravity and Pressure Sand Filter Suppliers[6]

Anthracite Filter Media Co.	734 E. Hyde Park Blvd., Inglewood, CA 90302
Calgon Corp.	Box 1346, Pittsburgh, PA 15230
Culligan Intl. Co.	One Culligan Pkwy, Northbrook, IL 60062
Delaval Turbine Inc.	Box 251, Trenton, NJ 08602
Dorr-Oliver, Inc.	77 Havemeyer Land, Stamford, CT 06904
Envirex Inc.	A Rexnord Co., 1901 S. Prairie Ave., Waukesha, WI 53186
Filtration Equipment Corp.	1425 Emerson St., Rochester, NY 14606
General Filter Co.	Arrasmith Trail, Box 350, Ames, IA 50010
Hungerford & Terry Inc.	226 Atlantic Ave., Box 45, Clayton, NJ 08312
Hydro Clear Corp.	Box 2360, Newport Beach, CA 92660
Infilco Degremont Inc.	Koger Executive Center, Box K-7, Richmond, VA 23288
Leopold Co.,	Division of Sybron Corp., 227 S. Division St., Zelienople, PA 16063
Midwest Marine Cont. Inc.	149 Gregory St., Mount Prospect, IL 60056
Neptune Microfloc Inc.	Subsidiary of Neptune Intl., Box 612, Corvallis, OR 97330
Peabody Welles, Inc.	11765 Main St., Roscoe, IL 61073
Permutit Co., Inc.	A Zurn Co., E. 49 Midland Ave., Paramus, NJ 07652
Roberts Filter Mfg. Co.	6th & Columbia Ave., Darby, PA 19023
Tonka Equipment Co.	5115 Industrial St., Maple Plain, MN 55359
The Turbitrol Co.	415 E. Paces Ferry Rd., Box 12047, Atlanta, GA 30355
Western Filter Co.	4545 E. 60th Ave., Box 16323, Denver, CO 80216

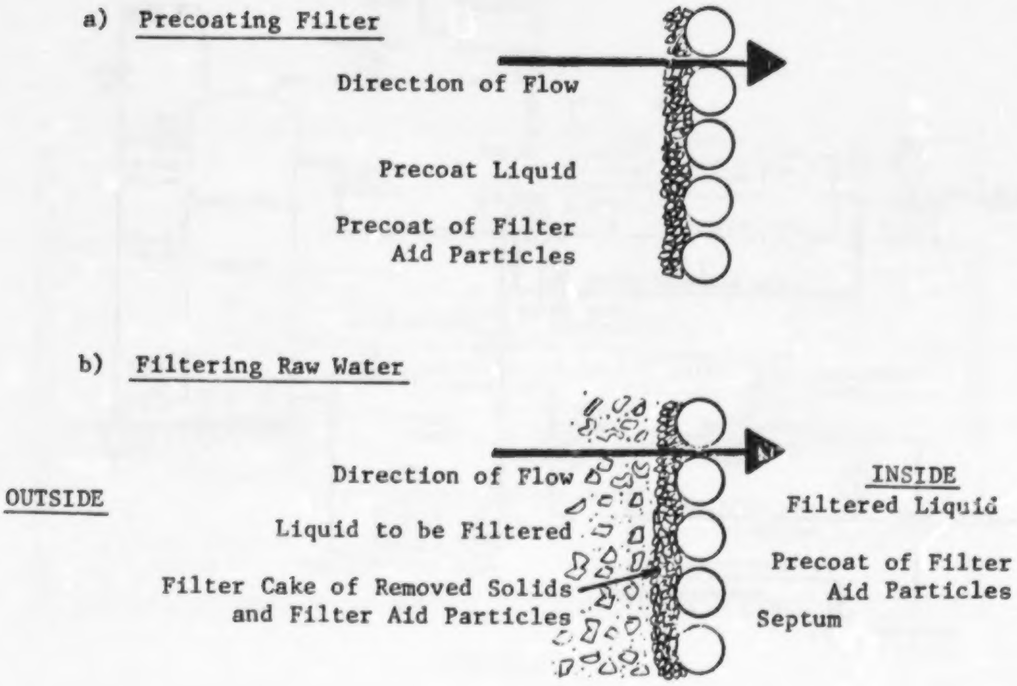

a) Precoating Filter
Direction of Flow
Precoat Liquid
Precoat of Filter Aid Particles
b) Filtering Raw Water
OUTSIDE
Direction of Flow
Liquid to be Filtered
Filter Cake of Removed Solids and Filter Aid Particles
INSIDE
Filtered Liquid
Precoat of Filter Aid Particles
Septum

Figure 25. Diatomaceous Filter Septum

Table 8
Partial List of Diatomite Filter Vendors[7]

Bif-Unit of General Signal	1600 Division Rd., West Warwick, RI 02893
Delaval Turbine Inc.	Box 251, Trenton, NJ 08602
General Filter Co.	Arrasmith Trail, Box 350, Ames, IA 50010
Hydro Clear Corp.	604 Moore Rd., Box 151, Avon Lake, OH 40012
Jones Chemicals Inc.	100 Sunny Sol Blvd., Caledonia, NY 14423
McKesson Chemical Co. [D]	Crocker Plaza, 1 Post St., San Francisco, CA 94104
Western Filter Co.	4545 E. 60th Ave., Box 16323, Denver, CO 80216

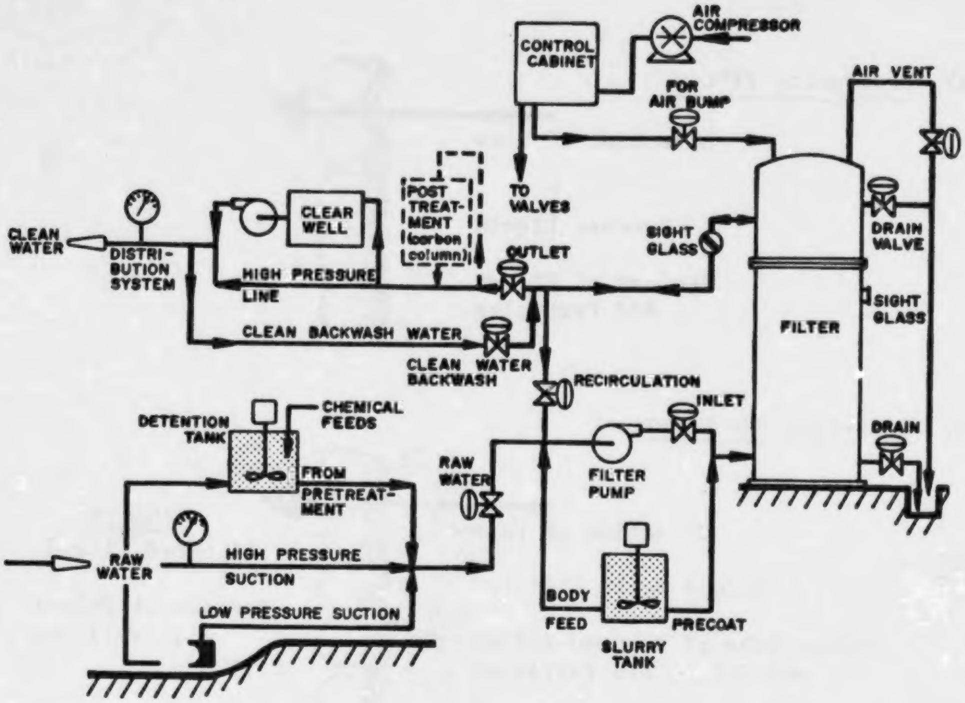
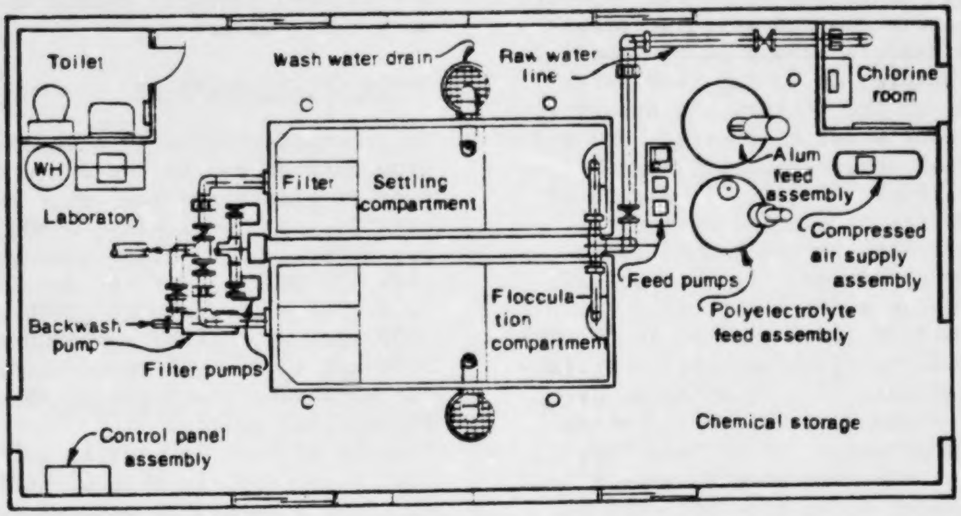

AIR COMPRESSOR
CONTROL CABINET
AIR VENT
FOR AIR BUMP
TO VALVES
POST TREATMENT (carbon column)
CLEAR WELL
CLEAN WATER
DISTRIBUTION SYSTEM
HIGH PRESSURE LINE
OUTLET
SIGHT GLASS
DRAIN VALVE
SIGHT GLASS
FILTER
CLEAN BACKWASH WATER
CLEAN WATER BACKWASH
RECIRCULATION
INLET
DETENTION TANK
CHEMICAL FEEDS
FROM PRETREATMENT
RAW WATER
FILTER PUMP
DRAIN
RAW WATER
HIGH PRESSURE SUCTION
LOW PRESSURE SUCTION
BODY FEED
PRECOAT
SLURRY TANK

Figure 26. Pressure Diatomite Filter

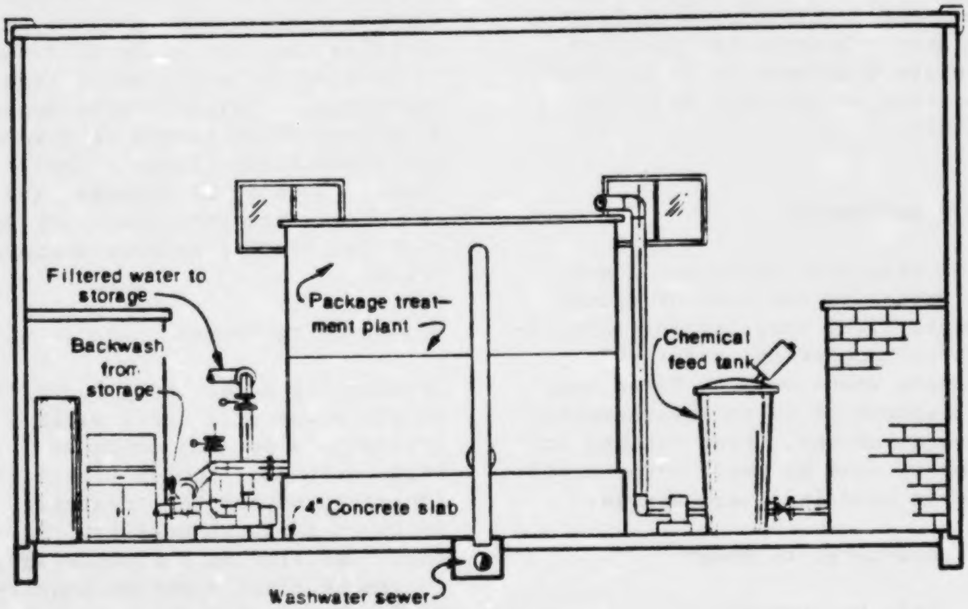
step basis. Traditionally, treatment plants have been custom designed, with each process considered as a separate step. Small water utilities, however, can select and purchase "packaged" systems, premanufactured and partly assembled before being shipped to the site. Packaged plant systems are usually constructed of protected steel and plastic and can be installed in simple prefabricated buildings. They are supplied complete with chemical mixing and feeding equipment, and controls, ready for installation.

Up to about 2 mgd (7570 cu.m./d) treated flow, packaged systems can offer substantial cost savings over custom designed and constructed plants. For example, a custom designed 1 mgd (3185 cu.m./d) plant which would have cost $1.1 million in 1978 could have been installed for $500,000 if a packaged system were used.[1,2] Reduced operator needs would cut operating costs by a third, due to the compact, easily maintained design of the plants and their semi-automatic control systems.

Figure 27 illustrates a typical layout of a packaged complete treatment system. This plant includes chemical mixing and feeding, coagulation, flocculation, settling, and filtration, plus controls, in a simple prefabricated type building. A cost estimating technique has been provided in Section V for this type of system.


Toilet
Wash water drain
Raw water line
Chlorine room
WH
Filter
Settling compartment
Laboratory
Alum feed assembly
Compressed air supply assembly
Feed pumps
Polyelectrolyte feed assembly
Backwash pump
Flocculation compartment
Filter pumps
Chemical storage
Control panel assembly

PLAN VIEW


Filtered water to storage
Package treatment plant
Backwash from storage
Chemical feed tank
4" Concrete slab
Washwater sewer

ELEVATION VIEW

Figure 27. Packaged, Complete Treatment System

DIRECT FILTRATION

The term "direct filtration" describes a turbidity removal process, which may eliminate separate flocculation and settling steps and features coagulation immediately before, or in the feed water side of the filter. It has received considerable interest, and widespread application by large water utilities.[16,17,18,19] Figure 28 compares direct filtration by comparison to the conventional process design. It is most suitable for surface waters of low turbidity (less than 50 to 60 NTU) caused by silt, or other coagulated solids.[16,19] A pilot study is recommended before selecting this process. It is important to note that this process generally requires close operator control. Packaged direct filtration plants are available; however, their manufacturers generally suggest that small water utilities with limited operator resources use packaged complete treatment as it is less sensitive to operator error or neglect.

WASTE MANAGEMENT

Water treatment processes generate wastes in the form of dilute sludges (from coagulation/flocculation/sedimentation) and turbid backwash waste water. These must be disposed of in an environmentally sound manner. Four options are commonly used by small water utilities in handling these wastes:

1. discharge to sewer
2. haul to landfill
3. lagooning
4. sand drying beds

Fortunately, water treatment plant wastes are generally low in organic content and free of toxic substances and do not require the specialized handling needed for more toxic wastes.

Waste Characteristics

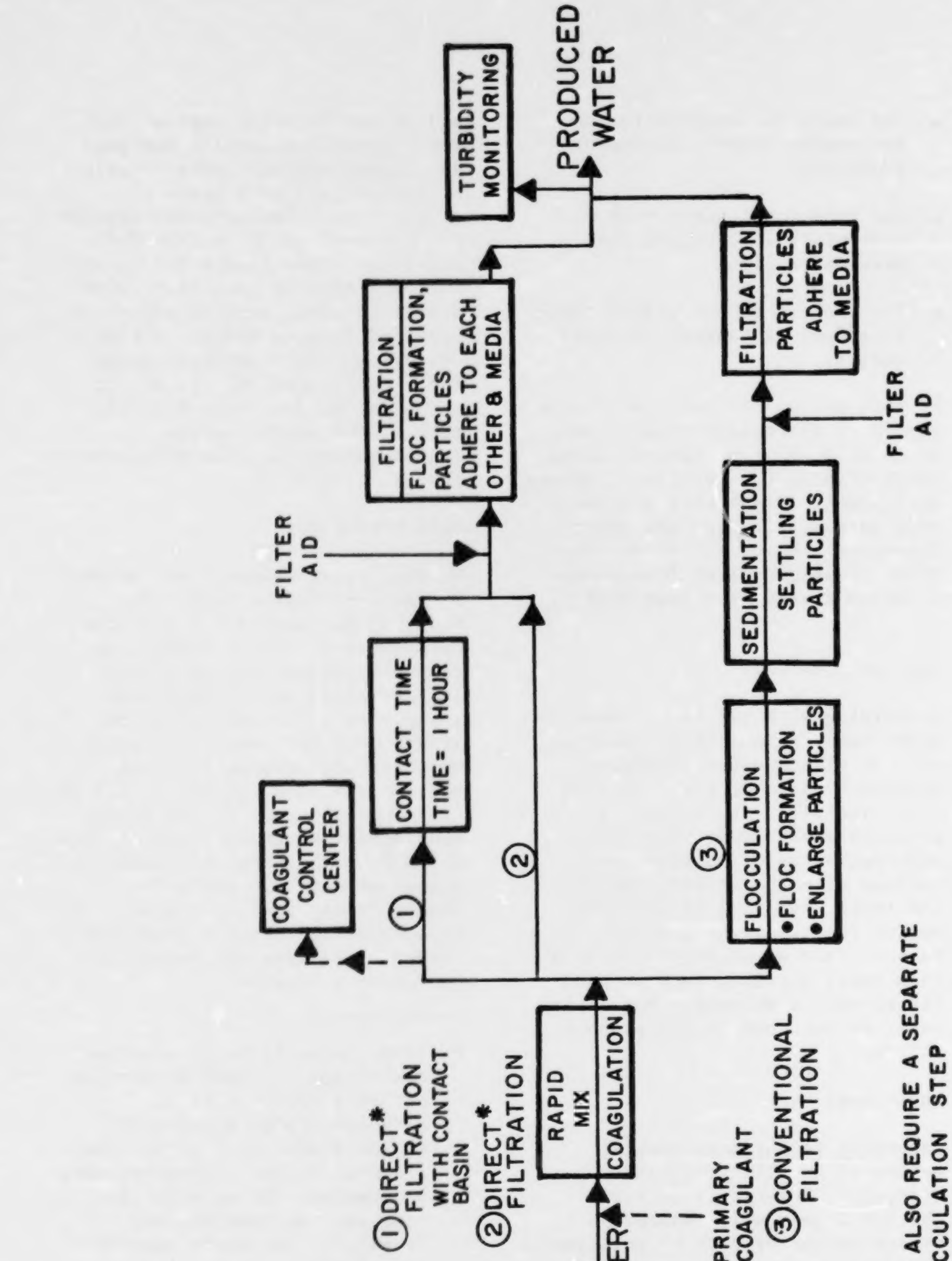
The characteristics of alum sludge from package plants depend on the type of plants and raw water characteristics. Typically, a 500,000 gpd (1892 cu.m.d) plant produces about 25,000 gallons per day (95 cu.m.) of dilute sludge (2000 to 5000 mg/l of solids) and 1000 to 2500 gpd (3.8 - 9.5 cu.m./d) of backwash waters containing 50 to 100 mg/l of solids.[11,12,20] Organic content is usually quite low, approximately that of effluent from a secondary wastewater treatment plant.

Sludge from alum treated waters appear as gelatinous greyish white slurries that are quite difficult to dewater (separate solid from the water). Larger plants employ a variety of machinery to dewater and concentrate sludge. Small plants, because of economic and O&M considerations, generally employ the simpler methods discussed below.

Discharge to Sewer:

Discharging water treatment wastes to the sewer of a local waste treatment plant may solve the waste disposal problem with little impact on wastewater treatment costs or effluent quality. In fact, settling at the waste water treatment plant might be improved.[20] Sewer discharge might be feasible if these conditions are met:

- Local sewers are capable of handling the sludge without blockage or excess scour.



① DIRECT* FILTRATION WITH CONTACT BASIN
② DIRECT* FILTRATION
③ CONVENTIONAL FILTRATION
RAW WATER
PRIMARY COAGULANT
RAPID MIX
COAGULATION
COAGULANT CONTROL CENTER
①
CONTACT TIME
TIME = 1 HOUR
②
FILTER AID
FILTRATION
FLOC FORMATION, PARTICLES ADHERE TO EACH OTHER & MEDIA
TURBIDITY MONITORING
PRODUCED WATER
③
FLOCCULATION
•FLOC FORMATION
•ENLARGE PARTICLES
SEDIMENTATION
SETTLING PARTICLES
FILTER AID
FILTRATION
PARTICLES ADHERE TO MEDIA
* MAY ALSO REQUIRE A SEPARATE FLOCCULATION STEP

Figure 28. Direct Filtration vs. Conventional Process Design

- The waste is amenable to the wastewater plant's treatment processes.

- The additional water will not hydraulically overload the wastewater plant.

- The waste does not significantly affect wastewater effluent quality.

If this option is used, the sludge should be discharged slowly, over an 18 to 24 hour period, to avoid shock loading the wastewater treatment plant. Use backflow prevention valves, air gaps and other appropriate means to protect the water treatment plant from contamination caused by sewage backup.

Haul to Landfill:

Localities with remote or nonexistent sewerage facilities can dispose of dilute water treatment sludges by land disposal in sanitary landfills. Reference 15 presents a cost model for this alternative based on tank truck haulage with the utility owning the truck. Hauling of backwash waters should not be required. Rather, this water should be held in a small settling tank or pond fitted with a skimmer. The clear water is returned to the process stream.

Lagooning:

Lagooning is the most popular method of handling coagulant sludges.[1] A large, relatively shallow lagoon will reduce the sludge volume by both evaporation and seepage into the ground. In addition, freezing of the pond's contents (in colder climates) may aid in solids/water separation.* The lagoons are usually designed as unlined earthen ponds capable of retaining 3 to 5 years of sludge flow. Two parallel lagoons are provided to allow time for cleaning. (See Figure 31) A surface skimmer, to facilitate withdrawal of clear surface water, is provided in each basin. Periodically, the plant operator pumps the excess water off, either to the plant headworks or directly back to the source stream (although this may require a discharge permit).

Sand Drying Beds:

Warmer, drier climates may be able to use sand drying beds. The beds, widely used for dewatering wastewater treatment sludge, are commonly constructed of 6 to 9 inches (15-23 cm) of sand overlying 9 to 12 inches (23-30 cm) of gravel used to cover drain pipes which convey seepage from the beds. Sand sizes of 0.4 to 0.5 mm are commonly used.[12] The drying beds appear as shallow basins into which 8 to 12 inches of sludge is pumped at a time. After the sludge dries, in 1 to 2 weeks, it is scraped off using a front end loader or similar equipment and hauled to a landfill.

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* If freezing is to be used for dewatering, it must be carried out on a batch basis as unfrozen sludge mixed with frozen sludge will negate the process. Further, freezing must be complete for an effective process. As snowfall may "insulate" the ponds contents from freezing, provision for snow removal may be needed if this process is used.

Sand drying beds require extensive space and long dewatering times and may perform poorly during cold or wet weather. The labor and equipment required to remove the sludge are expensive as well. Small water utilities should throughly investigate the alternatives discussed above before choosing sand bed dewatering.

IV. DESIGNING TURBIDITY REMOVAL SYSTEMS

INTRODUCTION

Design of water treatment systems entails several interrelated steps, as illustrated by Figure 29. The design process begins with complete characterization of system needs and constraints. Characterization data is used in selecting process and equipment for the treatment plant. The level and type of treatment needed largely determines equipment selection. The decision to use packaged versus custom designed systems depends mainly on site considerations, O&M resources, and cost considerations.

Water treatment plants using chemical coagulation generate significant quantities of waste which must be disposed in an environmentally sound manner. Fortunately, water treatment plant wastes rarely contain hazardous or toxic substances. Small systems generally produce relatively small quantities of wastes which can be safely disposed by landfilling or lagooning. Discharge of liquid wastes to a nearby wastewater treatment plant may also be possible. Other options include mechanical condensing and disposal systems which should be avoided if possible as they are more complex, costly and maintenance intensive.

This section of the text discusses design of treatment systems and equipment for turbidity removal. Emphasis is placed on packaged systems as they are generally the most economical and easy to operate for water utilities treating less than 500,000 gpd. Because packaged systems are pre-engineered, the discussion focuses on selection of the proper plant type, size and site requirements, for new or upgraded turbidity removal systems. At the conclusion of the section, Table 10 provides an example of the decision process that would be followed in designing a small packaged treatment system. Custom designed water treatment systems require a more extensive engineering effort and should be designed by professional consulting engineers with specific experience in their design and construction.

CHARACTERIZATION

Developing a complete understanding of the specific characteristics of the application is the key to subsequent decision making and system design. Time and money spent up front for this activity can avert costly and time consuming errors in design and operation of the plant.

Water Quality Analysis

Water quality analyses coupled with projection of current and future quantity and quality needs provides the primary basis for design. Analyze representative water samples to determine key turbidity related parameters. For example:

- Turbidity and Suspended Solids - used in process and coagulant selection.
- pH and alkalinity - key factors in coagulation chemistry and control.

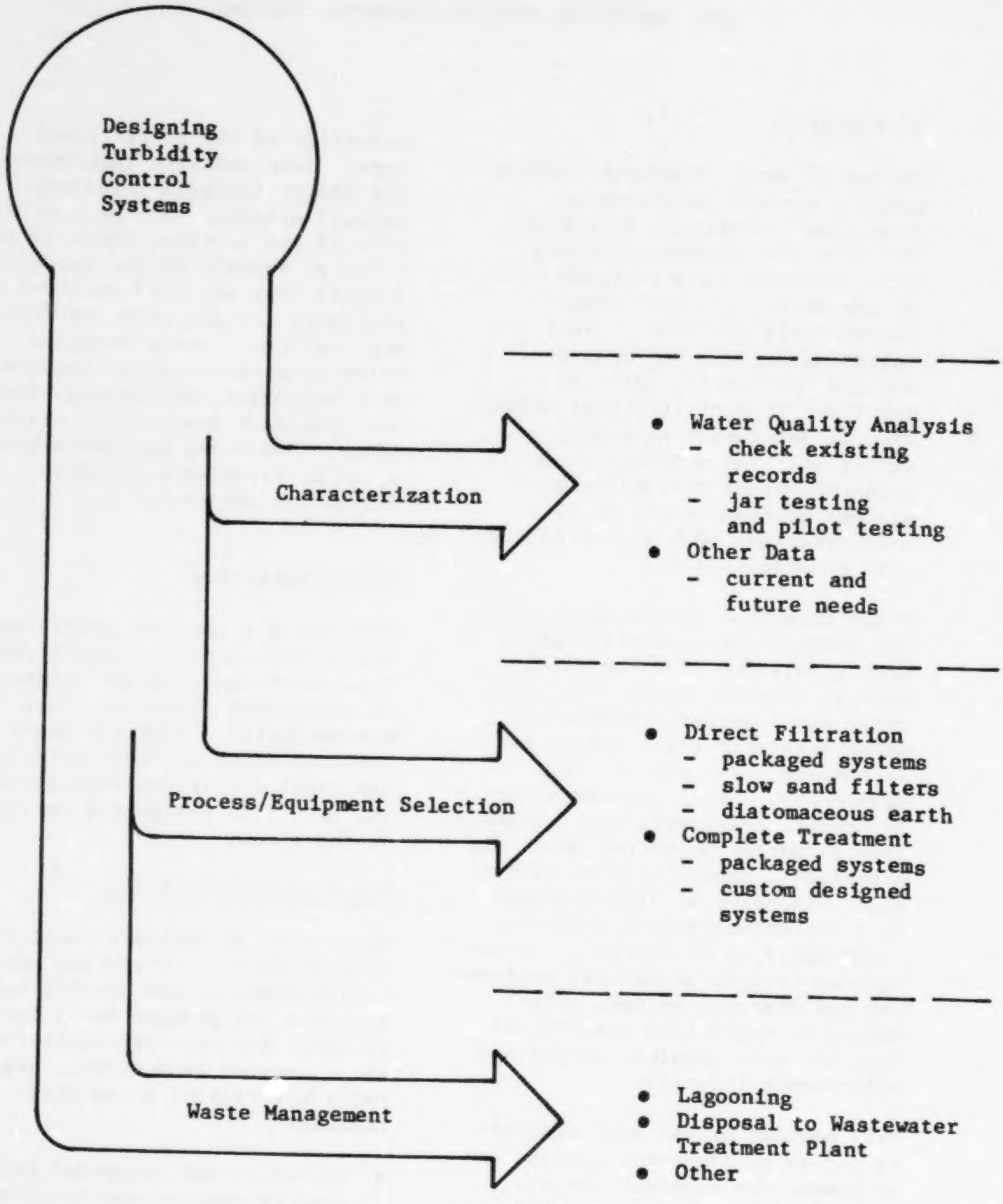
Designing Turbidity Control Systems
Characterization
• Water Quality Analysis
- check existing records
- jar testing and pilot testing
• Other Data
- current and future needs
Process/Equipment Selection
• Direct Filtration
- packaged systems
- slow sand filters
- diatomaceous earth
• Complete Treatment
- packaged systems
- custom designed systems
Waste Management
• Lagooning
• Disposal to Wastewater Treatment Plant
• Other

Figure 29. Design Process for Turbidity Control Systems

- Hardness and total dissolved solids - also affect coagulant chemistry.

- Sodium and chlorides - may affect coagulant selection because of consumer health considerations.

- Iron and manganese - excessive levels (over 0.3 mg/ for iron, 0.05 mg/l for manganese) may affect coagulation and may require additional treatment processes.

- Algae - excessive levels may affect treatment process and equipment selection and may require pretreatment.

- Organic compounds - additional treatment may be required for some organics.

Collect sufficient water sample data to characterize the full range of water quality that may occur. This is particularly important with suface water supplies, where key parameters can vary with weather, seasonal changes, and watershed development. Ground water tends to change much more slowly (in the absence of gross pollution).

Before setting up a sampling program, check all existing utility and state records for the results of previous analyses. Existing water utilities may already have adequate long-term data to provide the background needed for treatment design. Also, consult with the suppliers of the treatment systems that you are considering to find out their data needs for developing recommendations.

Jar Testing, described in Section III, is used to determine coagulant selection and dosage. Jar tests are also quite useful in identifying turbidity related water quality parameters that may interfere with the coagulation process. Expert assistance for jar testing may be available from chemical suppliers, packaged treatment system manufacturers or local water quality laboratories.

Pilot Testing is used to simulate the proposed treatment process on a small, low cost scale. Where water quality analysis or jar testing indicates potential problems with the proposed process, a pilot test might be indicated. The pilot plant would be set up to treat a small (usually less than 10 gpm, 37.8 l/min) using a model of the proposed process. Pilot testing is generally not required for most treatment system designs. However, if direct filtration is the preferred process, it may be advisable to pilot test it if jar test or water quality data indicate potential problems.

Other Characterization Data

The selection of appropriate treatment for new turbidity removal systems also depends on these factors:

- Plant size - hourly, daily, weekly and annual flow, seasonal variation expected; future demand growth.

- O&M resources - availability and funding to support full time trained plant operators and laboratory facilities.

- Site constraints - climate, land area, waste disposal constraints.

Is the expected growth in future water demand rapid, slow or unknown? The answer to this question determines how much capacity should be installed initially and the provisions needed for expansion. How much can the system afford for operating personnel and supporting laboratory equipment?

If O&M resources are severely limited, processes and equipment that minimizes O&M needs should be favored. Are there constraints unique to the locality or plant site that markedly impact design? If so, these should be communicated to plant engineers and potential equipment suppliers early in the design process.

PROCESS AND EQUIPMENT SELECTION

In selecting treatment processes and equipment, be guided first and foremost by the needs, constraints, and resources of your particular utility and regulatory agencies such as the State Health Department that may have jurisdiction. In most cases, one of the early decisions will involve the choice between "custom designed" plants (individually designed and conventionally constructed systems) versus "packaged" systems (engineered and manufactured in a factory and shipped to site by truck or rail). In the latter case, site work consists mainly of the plumbing, electrical, housing, road ways, and ancillary storage vessels that support the packaged plant. Because they can offer substantial savings in acquisition and operating costs,[1,2,13] packaged systems are frequently chosen by small water utilities. Regardless of the chosen option, however, the services of an experienced Professional Engineer will be needed for plant design, obtaining state approvals, and overseeing the installation of the plant.

Whether you elect to use a packaged system or a custom designed plant, you will have to select a treatment process that is best suited to your raw water quality and operational resources. Usually, you will be choosing between direct filtration and complete treatment options as discussed below and illustrated by Figure 30.

Direct Filtration For Low Turbidity Waters (<60 NTU)

In some cases, raw water quality and operational resources permit the use of less extensive treatment schemes based on filtration. Water of low turbidity(10 to 60 NTU) direct filtration may be a viable option, using multi-media filters and close operator supervision (see Figure 30). These systems may require flocculation for satisfactory performance. Some packaged direct filtration systems can be purchased with coagulation and flocculation chambers built into the filter body.

Very low turbidity water (<10 NTU) that does not vary drastically in quality over time and requires only minimal coagulation might be treated with simple, low-maintenance slow sand filters, or compact diatomaceous earth filters.

Consider using direct filtration if the following conditions are met:

Dual Media/Multi-media Sand Filters:

- low turbidity waters (10 NTU-<Turb.<60 NTU)
- relatively consistent and predictable raw water quality
- pilot study has established process feasibility and operational requirements

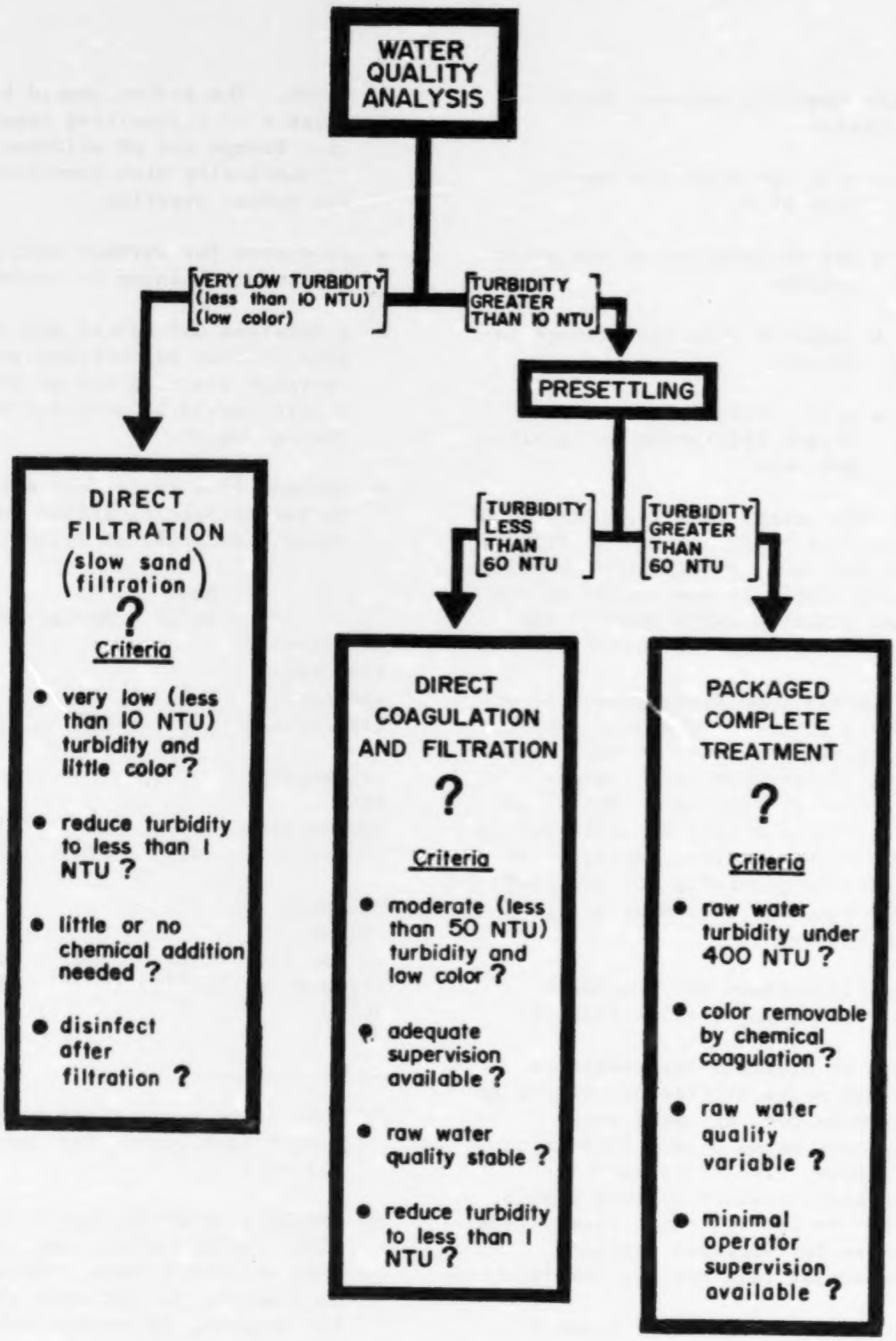
WATER QUALITY ANALYSIS
VERY LOW TURBIDITY (less than 10 NTU) (low color)
TURBIDITY GREATER THAN 10 NTU
PRESETTLING
TURBIDITY LESS THAN 60 NTU
TURBIDITY GREATER THAN 60 NTU
DIRECT FILTRATION (slow sand filtration) ?
Criteria
very low (less than 10 NTU) turbidity and little color ?
reduce turbidity to less than 1 NTU ?
little or no chemical addition needed ?
disinfect after filtration ?
DIRECT COAGULATION AND FILTRATION ?
Criteria
moderate (less than 50 NTU) turbidity and low color ?
adequate supervision available ?
raw water quality stable ?
reduce turbidity to less than 1 NTU ?
PACKAGED COMPLETE TREATMENT ?
Criteria
raw water turbidity under 400 NTU ?
color removable by chemical coagulation ?
raw water quality variable ?
minimal operator supervision available ?

Figure 30. Treatment Process Selection

Slow Sand/Diatomaceous Earth Filters:

- very low turbidity waters (<10 NTU).
- low variability in raw water quality
- required coagulant dosage is minimal
- pilot study indicates that direct filtration is feasible and safe

DO NOT SELECT DIRECT FILTRATION OF ANY TYPE UNLESS IT CAN BE CLOSELY SUPERVISED. PROVIDE CONTINUOUS ON-LINE TURBIDITY MONITORING OF RAW AND FINISHED WATER QUALITY AND AUTOMATIC CHEMICAL DOSAGE CONTROL.

If these conditions cannot be met, use a complete treatment system. Complete treatment is more forgiving of operator error and/or neglect of coagulant control and can tolerate greater variation in raw water quality. Also, pilot study is generally not required for complete treatment system application.

Specifications for Treatment Systems Using Gravity Filters:

Use of packaged dual media or mixed media filtration systems is recommended for small water systems using direct filtration systems. Specifications for packaged gravity filters should include the following items (plus those for packaged complete treatment that are applicable):

- There should be at least 5 years in service experience with the specified plant.
- A monitoring/control system for influent and effluent turbidity, flow and pH should be provided. The system should be capable of controlling coagulant dosage and pH adjustment automatically with provision for manual override.
- Provision for surface wash or air scour cleaning is needed.
- A detailed O&M manual and on-site startup supervision and operator training for at least 2 days should be provided with the equipment.
- Maximum flow rates (per manufacturers specifications and state standards) as follows:

	Dual Media	3 Media	4 Media
Maximum* Flow Rate gpm/sq.ft.	4	5	5
(lpm/sq.m.)	(163)	(204)	(204)
Backwash** Rate gpm/sq.ft.	10	17	19
(lpm/sq.m.)	(407)	(693)	(774)
Backwash Volume gal/sq.ft.	100	100	100
(1/sq.m. @ 70°F)	(4074)	(4074)	(4074)

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* Some state regulations allow only a 2gpm/sq.ft. (81 lpm/sq.m.) rate.

** Complete backwash specifications include cycle time, flow rate and total water consumpconsumption per backwash cycle. Air scouring is recommended for systems using in-line coagulation. Rotary surface washing should be provided on all filters.

Slow Sand Filter Specifications

Slow sand filters may be considered for use for water of less than 10 NTU turbidity, and requiring only minimal chemical treatment. Suggested specifications for slow sand filters include the following:[11]

Surface Loading	70-140 gpd/sq.ft. (2850-5700lpd/sq.m.)
Bed Depth*	24-42 inches (61-106 cm)
Effective Size of Sand	0.25-0.35 mm
Uniformity Coefficient of Sand	2-3

Slow sand filters are cleaned by scraping off several inches of surface sand after head loss has reached about 4 feet (1.2 m). Depending on cost and O&M considerations, the removed sand could be cleaned and replaced or disposed to landfill and replaced with fresh sand. The length of run between cleanings will probably range between 20 and 60 days.[11]

Diatomaceous Earth Filter Specifications

Diatomaceous earth filters merit close consideration for treatment of very low turbidity waters or for low cost upgrading of existing treatment systems (as an add-on final filter). Diatomite systems are available from a number of vendors as packaged systems (see Table 8). Suggested specifications for diatomite filters[14,19] include the following:

Surface Loading	1 to 2 gpm/sq.ft. 40.7-81.4 lpm/sq.m.
Precoat Thickness	1/16-1/8 inches (1.6-3.2 mm)
Body Feed Concen.	20 mg/l of Diatomite
Maximum Cake Thickness	1/2 inches (12.7 mm)
Minimum Spacing Between Filter Septums	1" (25.3 mm)

Available commercial diatomite filters use either manual or combinations of mechanical, air, and/or hydraulic cleaning. See Reference 20 and 21 for detailed suggested specifications for municipal diatomite filter installations.

Packaged Complete Treatment

As the name implies, complete treatment involves the use of the full range of processes: rapid mixing, chemical coagulation, flocculation, sedimentation, and filtration. Packaged complete treatment equipment is generally recommended for these conditions:

- For Turbidity Levels Up to 400 NTU - packaged complete treatment plants can handle turbidities from 10 to 400 NTU.
- Where Minimal Operator Supervision is Available - the plants are designed to operate semi-automatically with operoperator supervision limited to routine and repair maintenance.
- Where Raw Water Quality is Variable - complete treatment

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* Sand depth up to 42 inches (106 cm) which is reduced to a minimum of 24 inches (61 cm) by periodic scraping for cleaning before fresh sand is added.

systems can tolerate a wider range of turbidity and still produce water that meets NIPDWR standards. The plants are less sensitive to water quality variation than direct or in-line filtration.

- Where Color Removal is Required - A more controlled coagulation/flocculation/sedimentation process is required for effective color removal in most cases. Complete treatment is generally used for color removal.

Manufacturers of packaged complete treatment systems normally provide suggested plant layout drawings, including specifications for building size and special features needed to house the plant. These must be modified as needed to fit the requirements of your particular application.

NOTE: THE SYSTEM MANUFACTURER MUST BE GIVEN ADEQUATE WATER QUALITY DATA TO SIZE AND DESIGN THE UNIT PROCESSES. Jar tests are recommended before selecting a plant design.

Specifications for packaged complete treatment should include the following items (Table 9 summarizes some typical design parameters for both packaged and custom designed complete treatment systems):

- A monitoring/control system for influent and effluent turbidity. The system should be capacapable of reliably controlling coagulant dosage and pH adjustadjustment automatically with provision for manual override.

- Filter backwashing should be automatically initiated, with provision for manual override by the plant operator. Backwash rate, provided by the manufacturer, should not exceed 15 to 22 gpm/ sq.ft. of filter area (611-896 lpm/sq.m.) with a total water consumption of 100 to 150 gallons/sq.ft. per backwash cycle. The clear water (backwash water) storage tank should be separated from other parts of the plant either as a separate tank or at minimum, by a double bulkhead with a cavity drain. It should be sized to provide for at least 2 consecutive backwash cycles (or backwash water can be drawn directly from the finished water reservoir). Filters applied to high turbidity waters (over 200 NTU) should be provided with air scour and surface rotary spray washers.

- The manufacturer or design engineer should provide a detailed O&M manual and onsite startup and operator training to ensure that the plant is operated properly.

- The manufacturer should provide a listing of recommended spare parts for all system components. It is recommended that these be purchased and stocked at the time the plant is purchased.

- The manufacturer should be able to provide or arrange for the provision of factory service on the plant and its components. This is particularly important in the case of plant components that require specialized O&M skills, such as monitors and controls, and chemical metering pumps. **Do not purchase equipment from a manufacturer that cannot provide service.**

Table 9
Summary of Complete Treatment Design Data For Packaged and Custom Designed Systems

Complete Treatment	Packaged Systems[21,22,23]	Custom Designed Systems[11,12]
Coagulation/Rapid Mixing	Complete & homogeneous rapid mixing 10 to 30 seconds detention	Same
Flocculation	Up to 20 minutes	20 to 60 minutes detention 0.1 to 3 fps (3-91 cm/sec) Paddle area 10 to 25 percent of tank section area
Sedimentation	Tube or plate settlers 235 gpd/sq.ft. (9574 lpd/sq.m.) maximum surface loading rate	Surface loading rate - for alum sludge 360 to 547 gpd/sq.ft. (14,667-22,285 lpd/sq.m.) Detention 2 to 4 hours
Filtration (maximum rates)*		
Mixed Media:	5gpm/sq.ft. (204 lpm/sq.m.)	5 gpm/sq.ft. (204 lpm/sq.m.)
Dual Media:	4 gpm/sq.ft. (163 lpm/sq.m.)	4 gpm/sq.ft. (163 lpm/sq.m.)
Rapid Sand:	Not Recommended	2 gpm/sq.ft. (81.5 lpm/sq.m.)
Backwashing:	22 gpm/sq.ft. (896 lpm/sq.m.)	20 gpm/sq.ft. (815 lpm/sq.m.)
Chemical Feed/ Storage	Dependent on chemical chosen, raw water characteristics, storage needs of specific system.	Dependent on chemical chosen raw water characteristics, storage needs of specific system.

* Some state regulations specify design maximum filtration rates not to exceed 2 gpm/sq.ft. (81.51 pm/sq.m.)

- The manufacturer should have at least 5 years of in service experience with the treatment plant.
- Dual or mixed media filter beds as follows:[21,22]

Dual Media	Mixed* Media
6" anthracite	18"anthracite
18" silica sand	9"silica sand
	8"high density sand

- Maximum filter flow rates (per manufacturers specification and state standards), not to exceed 4 gpm/sq.ft. for dual media and 5 gpm/sq.ft. for mixed media.
- Chemical feed and mixing equipment sized at two times maximum coagulant flow, capable of mixing and storing a one day supply of coagulant(s)
- Rapid chemical mixing should be provided and the floccuation compartment should have at least 20 minutes detention with controlled mechanical stirring.
- Settling compartments should include tube or plate settlers. Loading rate should not exceed 235 gpd/sq.ft (9574 lpd/sq.m.) of face area.[23] Flocculated water should be evenly distributed across the face of the tube/plate assembly.

Figure 27, shown on page III-29 is a typical packaged treatment plant used to treat flows up to 100 gpm (144,000 gpd).

MONITORING AND CONTROL

Monitoring and control equipment for packaged or custom designed systems should include the following:

- A main control panel with switching and indicator lights for all pumps, motors and electrical controls.
- Automatic settled sludge pumping, with timers for setting cycle frequency and length, plus manual over-ride.
- Automatic backwashing of filters, initiated by filter head loss monitors with a manual override. Backwashing should be controlled by a programmable monitor controller which allows the operator to vary cycle times for each phase of the backwashing operation.
- Automatic continuous monitoring of raw and finished water turbidity with warning lights and/or alarms to alert the operator when influent turbidity varies by more than 20 percent or when treated water turbidity exceeds the 1 NTU standard.

Automated chemical feed equipment which is controlled by turbidity monitors is now available from some equipment vendors. As of 1981, it was still relatively unproven in long term field service. However, the status and availability of this equipment should be checked on when the system is being designed as it could be of great use to the operators by reducing the need for continuous and close supervision of chemical feeding.

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* Mixed media may be of either 3 or 4 layer type. For larger filters use two layers of differently sized anthracite.

WASTE DISPOSAL

Four alternate means of waste disposal were discussed beginning on page III-30. Of these, discharge to local sewers and lagooning are by far the most commonly used by small water utilities. This section will focus on lagooning.

Figure 31 depicts a typical site plan for a 250,000 gpd packaged complete treatment system with waste lagoons. Filter backwash waters are recycled to the raw water pre-settling and holding pond. Sludge from alum coagulation is stored in each of two sludge lagoons in turn, providing a total of 4 years storage of up to 600 gpd of alum sludge (volume after clear water skimming). Periodically, clear water is skimmed from the top of the pond using a skimmer arrangement such as the one shown in Figure 31. The clear water stream is returned to the presettling pond or back to the stream. The lagoons are designed to fill to a 5 foot maximum sludge depth, with an additional 2 feet of freeboard. Dirt needed to construct the 3:1 sloped walls is obtained by excavation of the lagoon bottom.

Operation of the lagoon system alternates between the two basins. After the first basin has reached capacity, the waste flow is diverted to the second basin. The first is allowed to stand for several seasons, or until the contents have dried suffiently to be removed by earth moving equipment and trucked to a landfill for final disposal. After cleaning, it is again available for service at such time as the second basin requires cleaning.

CORROSION PREVENTION

The combination of water plus corrosive coagulating chemicals results in a high potential for corrosion of metallic system components. Where packaged treatment systems are housed in weather tight buildings, care must be taken to prevent buildup of a moist and corrosive internal atmosphere which can damage equipment not directly in contact with water or chemicals (such as electrical controls, motor windings and instruments). Corrosion prevention specifications should include the following:

- All painted surfaces which contact the raw or treated water should be coated only with AWWA and FDA approved coatings for potable water service. Use high strength PVC or other plastic piping, containers, and fittings where practicable to minimize corrosion.

- Chemical feed lines should be as short and straight as possible. Provide for easy line cleaning.

- Use only chemical mixing, storage and feeding equipment suitable for chemical service. It should be constructed of polyethylene, stainless steel and other non-corroding materials.

- Electrical controls should be installed in air tight housings with internal humidity control as needed in moist climates.

- Provide an indoor humidistat controller with an exhaust fan to automatically vent excess moisture outside. In very damp climates, consider installation of a dehumidifier as well.

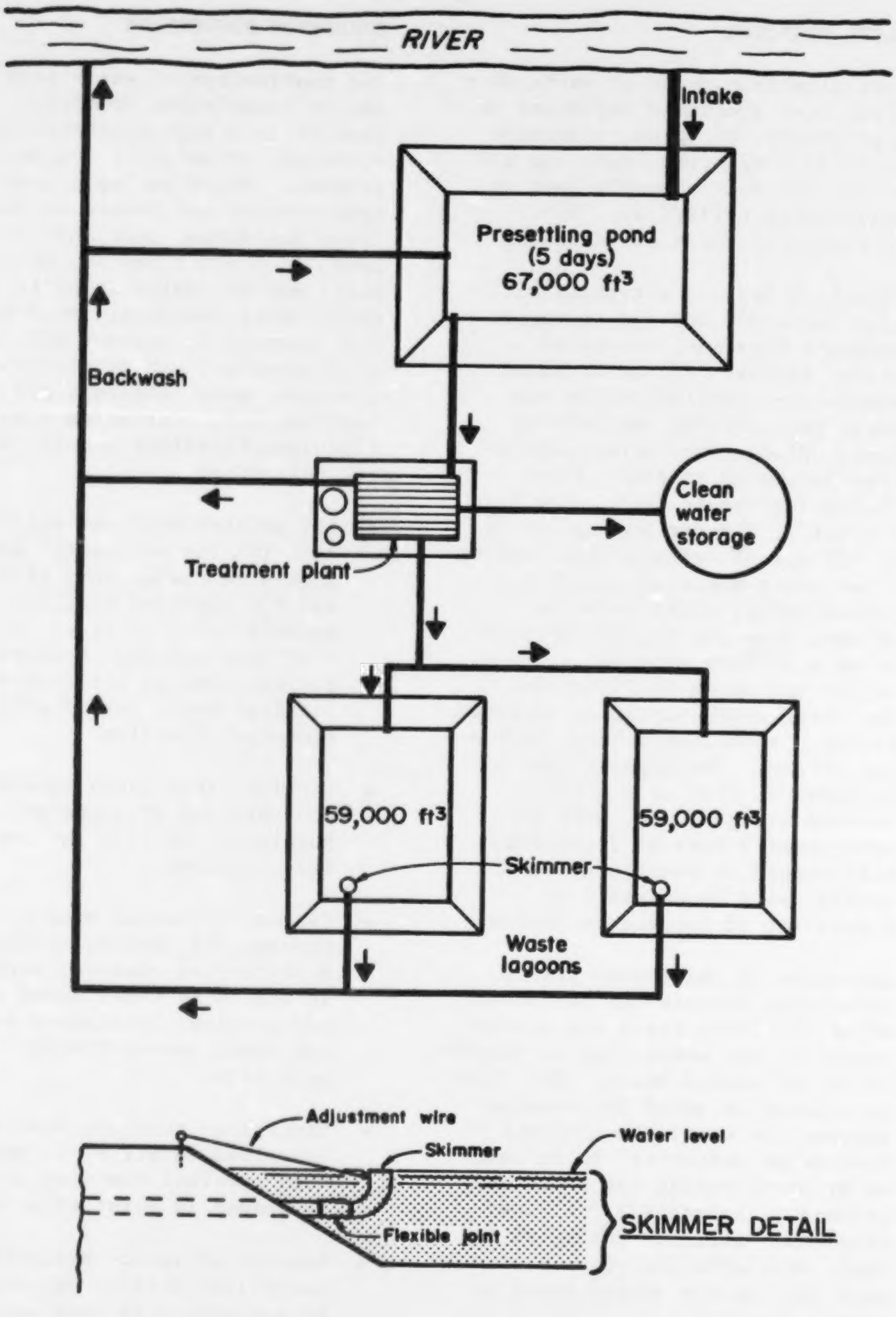
RIVER
Intake
Presettling pond
(5 days)
67,000 ft3
Backwash
Clean water storage
Treatment plant
59,000 ft3
59,000 ft3
Skimmer
Waste lagoons
Adjustment wire
Skimmer
Water level
Flexible joint
SKIMMER DETAIL

Figure 31. Site Plan of 250,000 gpd Packaged Complete Treatment Plant With Waste Lagoons.

OTHER DESIGN CONSIDERATIONS

These considerations should also be looked at when designing a small complete treatment or direct filtration plant:

- The plant layout should allow for the possibility of expan- expansion or addition of other treatment processes.
- Design the plant for intermittent operation, to allow time for routine and repair servicing, or provide duplicate process units (e.g., parallel package units).
- Provide a presettling pond of 2-5 days detention time if raw water quality is highly vari- variable. This will simplify operation and reduce chemical costs. Before using a holding pond for raw water, make sure that algae or other aquatic growths will not create water quality or operational problems.
- Provide for rapid flushing and disposal of chemical spills inside the treatment building. The floor should be equipped with floor drains connected to a holding tank and a sewer. Provide an emergency shower and eyewash fountain if concentrat- concentrated chemicals are used.
- Continuous influent/effluent turbidity monitoring is recommended. Where coagulation and pH control are required, this unit can be used to control chemical addition, reducing the direct supervision time required of the operator.
- Provide adequate equipment redundancy to assure uninterrupted treated water flow. Larger plants should employ parallel treatment units or provide 3 to 5 days clean water storage.
- Provide adequate climb proof fencing, lighting and entry control in and around the plant.
- All control switches and valves should be located so that they are protected from wetting and can be reached by an operator standing on the plant floor.

TABLE 10

SYSTEM DESIGN APPROACH FOR SMALL WATER SYSTEMS

STEP 1: OBTAIN ALL REQUIRED BACKGROUND DATA

- A. Water quality data:
  - 1. Review all existing records.
    - (a) Existing water utility files.
    - (b) EPA/State/local regulatory agency files.
    - (c) Records of other local utilities that use the same raw water source.
    - (d) (ground water supply) Information from local well drilling companies.
  - 2. Perform all other required analyses.
- B. Site data:
  - 1. Soils, topography, ground water and percolation data.
  - 2. Location and boundaries of any nearby floodplains.
  - 3. Access to supporting utilities such as gas, electric, roads, landfills.

STEP 2: PRELIMINARY STUDIES

- A. Identify and contact 3 or more suppliers of packaged water treatment systems:
  - 1. Provide each supplier with a summary of existing water quality conditions and the expected range of the data.
    - (a) Water quality data.
    - (b) Water source hydrology.
  - 2. Provide each supplier with a summary of pertinent site conditions.
    - (a) Climate.
    - (b) Any special soil conditions that impact on foundation design.

(continued)

TABLE 10
(continued)

  - (c) Any constraints on the availability of supporting utilites.
  - (d) Special conditions imposed on plant operations by adjoining land use (ie. noise, dust, traffic).

3. Provide any additional data requested by suppliers.

B. (Optional) Coagulation testing:

1. If raw water conditions are unusual, or if system manufacturers recommend it, conduct jar test to determine types and quantities of coagulating chemical(s) needed.
  - (a) Determine if jar testing can be carried out by equipment or coagulating chemical suppliers.
  - (b) Contact state or local regulatory officials for the names of qualified local labs (including local college labs).
  - (c) Determine the price and local availability of the common coagulating chemicals (ie. alum, polymers) and conduct jar tests as needed to determine the dosages and combinations of coagulants to be used. (Note: Local chemical suppliers are often excellent sources of information on the best chemicals and combinations available.)

STEP 3: PROCESS AND EQUIPMENT SELECTION

A. Review water quality and hydrologic data and categorize the water supply:

1. Average turbidity (up to 200 NTU), no unusual conditions.
2. Low turbidity (up to 60 NTU), no unusual conditions.
3. Very low turbidity (up to 10 NTU), no unusual conditions.
4. Unusual or highly variable water quality.

B. For average turbidity waters:

1. Evaluate the packaged complete treatment systems offered by at least 3 manufacturers.

(continued)

TABLE 10
(continued)

(a) Provide each with the data obtained in Steps 1 and 2 and any additional data or water samples requested by them.

(b) Obtain a listing from each of water treatment plants using their equipment and identify those plants in your locality that are treating similar quality waters.

(c) Contact a representative sampling of the plants for performance and O&M data:
  (1) Ability of plant to consistently produce waters of acceptable quality.
  (2) Required levels of operator supervision.
  (3) Any special maintenance problems and weak or trouble prone components.

(d) Visit 1-2 plants from each suppliers list and meet with the operational personnel directly responsible for running the plant to determine their operation and maintenance experience.

(e) Request a system proposal from those manufacturers whose plants are performing satisfactorily in the field. The system proposal should include:
  (1) Details of the process flow schematic, layout and site requirements for the model of plant proposed.
  (2) Description of the design basis of the major plant elements:
    - chemical mixing and feeding
    - coagulation/rapid mixing
    - design of settler and loading rates
    - provisions for desludging and cleaning settler
    - design of filter and loading rates
    - filter backwash system layout, controls, wash water flow rates, projected wash water consumption per cycle
    - controls and instrumentation normally provided with the plant and recommended options
    - recommended operator supervision and preventive maintenance.
    - recommended spare parts.
    - availability and description of local and/or factory service.

(continued)

TABLE 10
(continued)

- (3) Recommended supporting facilities and instrumentation.
- (4) Budget price and normal delivery times from receipt of written order.

C. For low turbidity waters:

1. Evaluate packaged direct filtration alternatives and compare to an evaluation of packaged complete treatment performed as per B above (Note: The complete treatment system supplier can often provide an alternative recommendation and proposal for direct filtration).

2. Conduct the evaluation for at least 3 suppliers of direct filtration equipment as outlined in B above (Note: Delete those items related to the settler as direct filtration does not utilize a separate settling unit).

D. For very low turbidity waters:

1. In addition to packaged direct filtration alternatives, evaluate the following:

   (a) Slow sand filtration.

   (b) Diatomaceous earth filtration (Note: Diatomaceous earth filter systems are often supplied in the form of packaged direct filtration systems, and can be evaluated using the same approach).

2. Slow Sand Filtration:

   (a) All slow sand filtration systems are custom designed. The design consultant should prepare a preliminary design and cost evaluation tailored to the specific requirements of the project.

3. Diatomaceous Earth Filtration:

   (a) The evaluation should include close review of the system's consumption of diatomaceous earth and the disposal requirements and cost for handling spent earth.

   (b) Availability and long term reliability and price of diatomaceous earth supplies should be checked carefully before selecting this alternative.

(continued)

TABLE 10
(continued)

E. Unusual or variable water quality:

1. This situation will require the services of a design consultant who is expert in the design of water treatment processes and plants. Although the final solution may use packaged components, the overall process and plant design may require additional specialized water quality analysis or pilot study, as well as custom design of critical plant elements.

STEP 4: FINAL DESIGN

A. After selection of the preferred alternative, the design consultant proceeds with the final project design and the preparation of detailed drawings and specifications. This includes sitework, design and specification of supporting facilities such as raw water storage and intake headworks, utility hookups, roadways and buildings, chemical storage, clear water storage and pumping, disinfection, etc.

B. The detailed final plans and specifications must be reviewed and approved by State regulatory authorities prior to bidding, contractor selection, and construction.

V. COST ESTIMATING PROCEDURES AND FUNDING SOURCES

This section provides a summary of the kinds of costs that are likely to be encountered in any treatment facility construction project and outlines a procedure to estimate costs associated with treatment for turbidity removal. It also summarizes some estimated construction and operating costs which have been made for the following treatment alternatives and provides an overview of potential funding sources for small water utilities.

- Package Gravity Filters
- Package Pressure Diatomite Filters
- Package Complete Treatment Plants
- Sludge Disposal Lagoons

Additional cost information, on actual operating plants, is given in Section VII. Table 20, at the end of the cost section, provides an example of cost analysis using the cost data presented in this chapter.

Costs depend largely on site specific conditions, some of which may change over time. The cost estimates in this report were based on assumptions made when the cost curves were developed (1976-78). In this regard, other projects are currently in progress to refine and improve the accuracy of cost estimating procedures. As these projects are completed they should be consulted for more accurate cost estimation procedures.

The total cost estimate for a water treatment facility is generally the sum of the costs associated with two major categories: (1) Construction Costs, and (2) Operation and Maintenance Costs. Each of these major cost categories is composed of individual costs for a number of components. To arrive at a total cost estimate for a given facility, the component costs are evaluated, adjusted as necessary for site specific considerations and inflation, then summed. Costs can be expressed many ways but annual cost, and cost per thousand gallons treated are two of the most common. The latter can be used directly to estimate the effect the project will have on the individual consumer's water bill. However, cost curves are generally most useful for comparing relative costs of the treatment alternatives and for approximating the general cost level to be expected for a proposed treatment system.

CONSTRUCTION COSTS

Introduction

Whenever treatment costs are determined, whether from a published report or a vendor's estimate, it is extremely important to establish exactly what components and processes the cost estimate includes. Different cost estimates based on different components (such as housing) have in the past resulted in many misunderstandings. In addition, if the costs are taken from a report, it is important to be sure they apply to the size category of your system. Once this has been ensured, cost comparisons between alternatives can be made using the process outlined in the introduction above. To illustrate this procedure, the cost information developed by the EPA Municipal Environmental Research Laboratory (presented in a 4-volume report titled: Estimating Water Treatment Costs, EPA-600/2-79-162)[15] can be used. This report presents cost curves for 99 unit processes useful for removing contaminants covered by the NIPDWR.

The construction cost curves for Reference 15 were developed by using equipment cost data supplied by manufacturers, cost data from actual plant construction, published data, and estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards, Mean's Building Construction Cost Data, and the Dodge Guide for Estimating Public Works Construction Costs. The construction cost curves were then checked and verified by an engineering consulting firm.

Adjustment of the cost curves may be necessary due to site-specific considerations such as geographical or local conditions, stand-by power requirements, and increases in the construction cost index as a result of inflation. The construction cost curves are particularly useful for comparing relative costs of the treatment alternatives and for evaluating the general cost level to be expected for a proposed treatment system.

Reference 15 Cost curves were all based on October 1978 dollars. The costs contained in these curves can be updated by using the Engineering News Record(ENR), Construction Cost Indexes (CCI), or Building Cost Index (BCI). Both indices utilize a single ratio to update costs. Note that these indices average cost figures from 20 cities--there is wide variation among individual cities and regions of the U.S. For example, the August 1981 CCI varied from a low of 274 to a high of 360 among the 20 cities, about a 31 percent difference. As a result, updated cost figures using this adjustment may tend to over or underestimate costs depending on the locality of interest. More sophisticated cost updating techniques are also available and are described in Reference 15.

The following formula applies the ENR CCI (base year 1967 = 100). To update the October 1978 construction costs simply multiply them by the current index and divide by the October 1978 index:

$$\text{Cost from curve X } \frac{\text{Current ENR CCI}}{265.38^{*}}$$

As of June, 1982, the ENR CCI stood at 359.92. Thus, to update the Reference 15 cost estimates to this date, you would multiply them by 359.92/265.38 or 1.33. For more precise adjustment, use the current and October 1978 CCIs for the city/region that most closely approximates your own.

The construction costs cited in this document from Reference 15 are developed from 8 principal components:

Excavation and Site Work. This category includes work related only to the applicable process and does not include any general site work such as sidewalks, roads, driveways, or landscaping.

Manufactured Equipment. This category includes estimated purchase costs of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

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* October 1978 ENR CCI was 265.38 for 20 city average.

Concrete. This category includes the delivered cost of ready-mix concrete and concrete-forming materials.

Steel. This category includes reinforcing steel for concrete and miscellaneous steel not included within the manufactured equipment category.

Labor. The labor associated with installing manufactured equipment, and piping and valves, constructing concrete forms, and placing concrete and reinforcing steel are included in this category.

Pipe and Valves. Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included within this category.

Electrical Equipment and Instrumentation. The cost of process electrical equipment, wiring, and general instrumentation associated with the process equipment is included in this category.

Housing. In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and the slab and foundation.

The total for construction cost using these cost components includes the costs of materials and subcontractors overhead and profit, to which is added 15 percent for miscellaneous items and contingencies.

The construction cost curves do not include the following items:

Special Sitework
General Contractor Overhead and Profit
Engineering
Interest
Land
Legal, Fiscal, Administrative Services

These are not directly applicable to the costs for specific processes. Rather, they should be added in after process costs have been estimated. Typically, these will average 30 to 35% of the total construction cost.

Package Gravity Filters

The configuration cost estimated in Reference 15 could be used for either direct or inline filtration (p. III-29). Construction cost estimates assume that the package gravity filtration plant is preceded by a one hour detention basin. Flow capacity assumed is 80* to 1400 gpm (5-88 l/s) at filtration rates of 2 and 5 gpm/sq.ft. (81.5-203.7 lpm/ sq.m.) of filter surface area. Table 11 summarizes the design assumptions used to make the cost estimates.

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* At flows below 80 gpm (5 l/s), use a packaged complete treatment plant.

Table 11
Package Gravity Filter Plants Design Concept[15]

Plant Capacity (gpm)		Number of Units	Filter Area (sq.ft.)	Diameter (ft.)	Total Filter Area (sq.ft.)	Housing Area (sq.ft.)
2 gpm/sq.ft.	5 gpm/sq.ft.					
80	200	2	20	5	40	1,500
140	350	2	38	7	76	1,800
225	560	2	50	8	100	1,800
280	700	2	79	10	158	1,800
560	1,400	3	113	12	339	3,600

NOTE: 1 gpm = 0.061 l/s
1 gpd = 0.003785 cum/d
1 ft = 30.48 cm
1 sq.ft. = 0.0429 sq. m.

The equipment cost estimates of Reference 15 include the following items:

- shop fabricated, open type, cylindrical steel tanks sized to permit over the road shipment.
- mixed granular filter media
- piping, valves and controls
- backwash and surface wash system
- chemical feed system (alum, soda ash, polymer, chlorine)
- raw water pumps
- backwash water storage
- building
- other items needed for a complete and operable installation

Cost curves are presented in Figure 32 for the two flow rates. It is recommended that you select the lower flow rate if you want to maximize time between filter backwashing. Using the higher rate, where allowed, will reduce the size and capital cost of the plant. Table 12 gives the cost breakdown for 80 to 560 gpm plants (5-35 l/s).

Package Pressure Diatomite Filters

Construction costs shown in Figure 33 and Table 13 assume a 1 gpm/sq.-ft. septum area flow rate. Cost estimates are for a complete installation, including diatomaceous earth storage, preparation and feed equipment, filters, supply pumps, valves and piping, and controls. Housing costs assume enclosure in a modular steel building with minimum space needed for maintenance. The conceptual design assumes one filter up to 380,000 gpd (1463 cu.m./d) and two up to 560,000 gpd (2156 cu.m./d). The required housing area ranges from 260 to 500 square feet (24.2-46.4 sq.m.).

Package Complete Treatment Plants

Cost estimates assume standard manufactured units with rapid mixing, 20 minutes of flocculation, sedimentation in tube settlers rated at 150 gpd/sq.ft. (6111 lpd/sq.m.) tube surface area, mixed media filters operated at either 2 or 6 gpm/sq.ft. (81.5-203.7 lpm/sq.m.). The cost estimates include the following items:

- premanufactured treatment tanks
- mixed media filter materials
- chemical storage tank and feed pumps
- flow measurement and control devices
- pneumatic air supply (200 gpm, 12.6 l/s and larger plants) for valve and control devices
- all controls
- buildings

The plants listed in the first two columns of Table 14 have low head filtered water transfer pumps and are designed to discharge to an above ground clear well. Larger plants are assumed to have gravity flow to an inground clearwell. Figure 34 shows cost curves for plants with filters loaded at either 2 or 5 gpm/sq. ft. (81.5-203.7 lpm/ sq.m.).

Sludge Dewatering Lagoons

Construction costs assume 7 feet (2.13 m) deep unlined earthen

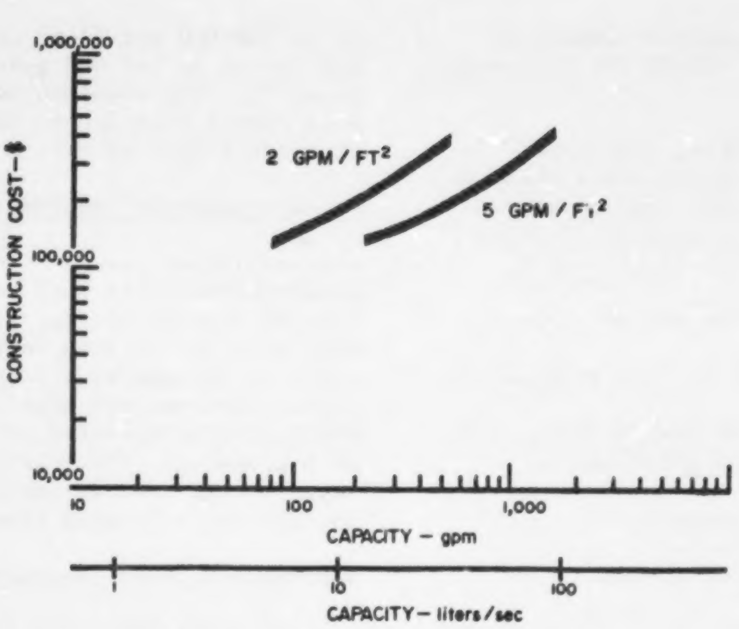

Figure 32. Construction Cost for Package Gravity Filtration Plants[1]

Table 12[15]
Itemized Construction Costs for Package Gravity Filter Plants

Cost Category	Plant Flow Rate (gpm) 80* and 200+	 140* and 350+	 225* and 560+
Excavation & Sitework	830	1,140	1,510
Manufactured Equipment	28,640	37,130	40,310
Concrete	14,840	20,670	28,090
Labor	11,800	13,340	14,330
Pipe and Valves	6,870	8,910	11,810
Electrical & Instrumentation	20,410	26,070	32,450
Housing	48,190	57,830	57,830
SUBTOTAL	131,580	165,909	186,330
Miscellaneous & Contingency	19,740	24,750	27,950
TOTAL	151,320	189,850	214,280

* Lower capacity represents a filtration rate of 2 gpm/sq.ft.
+ Higher capacity represents a filtration rate of 5 gpm/sq.ft.

Table 13[15]

Itemized Construction Costs for Package Pressure Diatomite Filters

	Plant Capacity (gpd)		
Cost Category	28,000	140,000	560,000
Excavation & Sitework	200	220	320
Manufactured Equipment	17,250	32,600	71,400
Concrete	200	250	380
Steel	100	130	170
Labor	4,500	5,200	6,300
Pipe & Valves, Pumps	1,500	1,800	3,100
Electrical & Instrumentation	2,500	2,800	4,200
Housing	13,850	13,850	16,600
SUBTOTAL	40,100	56,850	102,470
Miscellaneous & Contingency	6,020	8,530	15,370
TOTAL	46,120	65,380	117,840

NOTE: 1 gpm = 0.0631 l/s
1 pgd = 0.003785 cu.m./d
1 gpm/sq.ft. = 40.74 lpm/sq.m.

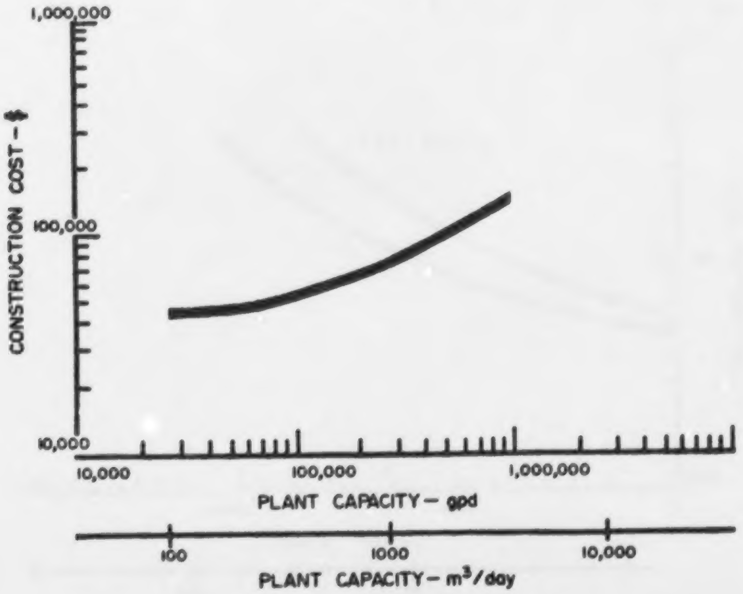

Figure 33. Construction Cost for Package Pressure Diatomite Filters[15]

Table 14[15]

Itemized Construction Costs for Package Complete Treatment Plants

Cost Category	Plant Capacity (gpm) 4* and 10+	 40 and 100	 140 and 350
Excavation & Sitework	210	390	810
Manufactured Equipment	13,050	30,770	72,140
Concrete	370	690	1,950
Labor	5,360	7,360	14,290
Pipe & Valves	1,060	1,590	3,610
Electrical & Instrumentation	16,360	21,580	26,990
Housing	15,960	21,740	48,840
SUBTOTAL	52,370	84,120	168,630
Miscellaneous & Contingency (@ 15%)	7,860	12,620	25,290
TOTAL	60,230	96,740	193,920

* Lower capacity represents a filtration rate of 2 gpm/sq.ft. (81.5 lpm/sq.m.)

+ Higher capacity represents a filtration rate of 5 gpm/sq.ft. (203.7 lpm/sq.m.)

NOTE: 1 gpm = 0.0631 l/s
1 gpd = 0.003785 cu.m./d

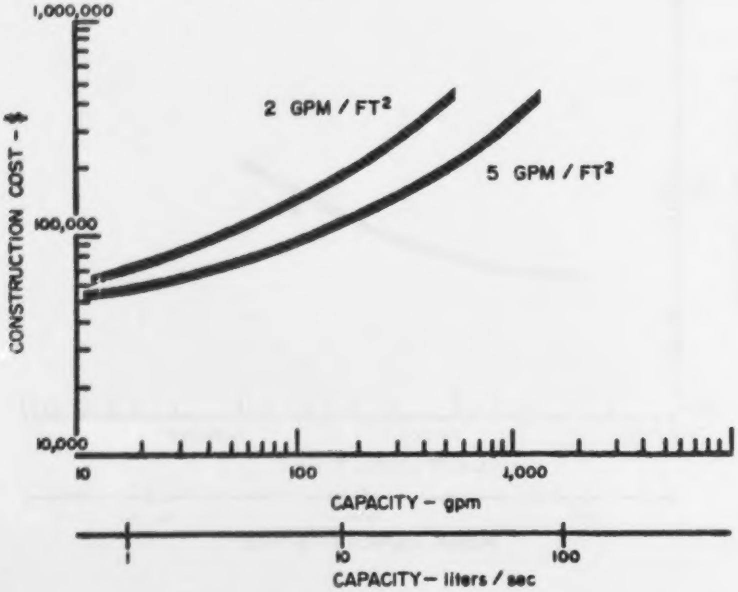

Figure 34. Construction Costs for Package Complete Treatment Plants[15]

basins with 2 feet (61 cm) of free board (unused depth). Dike sideslope is 3:1 and dike materials are assumed obtained from on-site excavation. The lagoon is provided with inlet and clear water skimming. Costs per lagoon are a function of effective volume (volume at 5 foot (1.5 m) depth, not including freeboard volume). Since sludge lagoons are typically dewatered every several years for sludge removal, a minimum of 2 lagoons should be provided. Land costs are not included. Table 15 contains the itemized costs used to obtain the cost curve of Figure 35. The Table provides a cost breakdown for 5 sizes of sludge lagoon.

Annualizing Capital Costs

Although capital costs are given as a lump sum, one time cost, water utilities usually operate on an annual (yearly) budget cycle. Thus, to state the total cost of treatment (capital plus O&M) on a yearly basis, the capital cost must be restated in terms of an annual equivalent payment over the life of the system in years (n), allowing for the cost of money, or interest (i). If the water utility choses to borrow the entire capital cost and pay it back in the form of equal payments over the project life, the amount of capital repaid (or recovered), plus the interest cost is determined by multiplying a Capital Recovery Factor (CRF) times the lump sum cost of the facility:

Annual Capital Cost = CRF X Lump Sum Capital Cost

In turn, the CRF is a function of the project life in years (or payback period) and the cost of money, i interest.

$$\mathrm{CRF} = \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

Many economics handbooks provide tables of CRF values corresponding to various combinations of interest and project life. Table 16 is an example of this type of table, condensed from Reference 23. The cost example of Table 20 shows how this table can be used to find the annual cost equivalent of a proposed system's capital cost estimate.

OPERATION AND MAINTENANCE COSTS

To obtain a total operation and maintenance (O&M) cost, the individual costs for energy (process and building heating), maintenance material, and labor must be determined and summed.

Total Operation and Maintenance costs from a reference document or previous contractor's estimate can be updated and adjusted to local conditions by updating and adjusting the operation and maintenance cost components: energy, labor and maintenance materials. Energy and labor requirements are generally provided in kilowatts per year and hours per year respectively and the curves from Reference 15 provide these as a function of plant size. To use this type of curve, the annual consumption is multiplied by the current energy or labor costs.

Maintenance material costs are related to as the Producer Price Index (PPI) for Finished Goods. To update this component, the PPI at the time the original cost estimates were made must be known. Then the new annual cost is determined by multiplying the cost from the graph by the ratio of the new PPI divided by the PPI at the time

Table 15[15]

Itemized Construction Costs for Sludge Dewatering Lagoons

Cost Category	Effective Lagoons Volume (cu.ft.)				
	1,500	3,500	5,000	17,000	30,000
Excavation & Sitework	500	650	700	1,300	2,000
Concrete	300	300	300	350	600
Pipe & Valves	600	600	600	750	900
Labor	400	500	650	1,000	1,800
SUBTOTAL	1,800	2,100	2,250	3,400	5,300
Miscellaneous & Contingency (@ 15%)	270	320	340	510	800
TOTAL COST	2,070	2,420	2,590	3,910	6,100

NOTE: 1 cu.ft. = 0.028 cu.m.

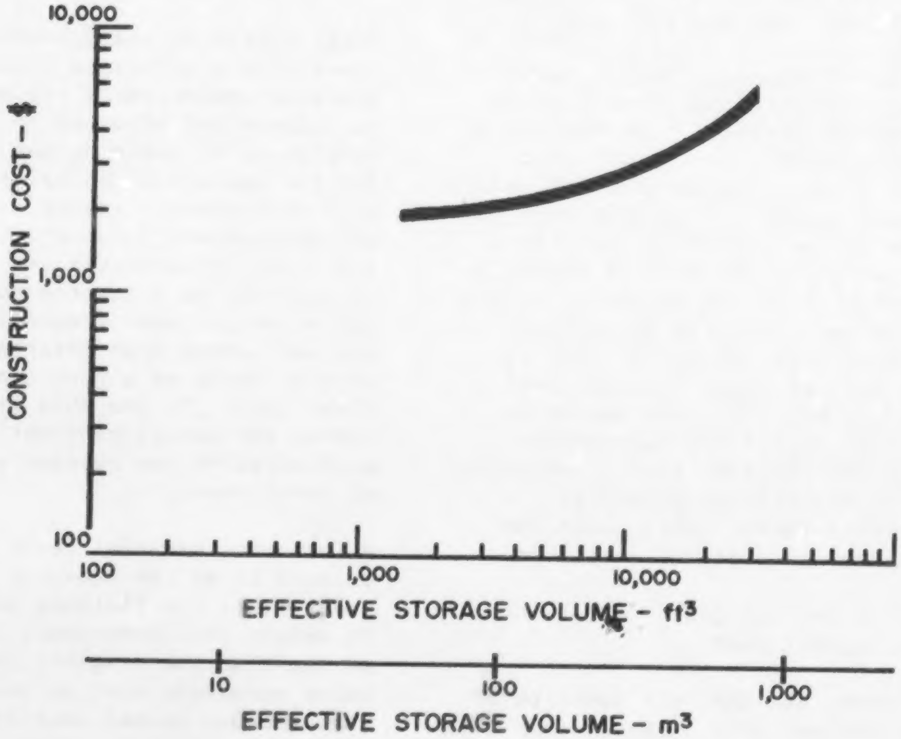

Figure 35. Construction Costs for Sludge Dewatering Lagoons[15]

Table 16[23]

Capital Recovery Factors for Some Combinations of Interest (i) and Project Life (n)

	Capital Recovery Factor					
n Years	6%	7%	8%	9%	10%	12%
5	0.237396	0.243891	0.250456	0.257092	0.263797	0.277410
10	0.135868	0.142378	0.149029	0.155820	0.162745	0.176984
15	0.102963	0.109795	0.116830	0.124069	0.131474	0.146824
20	0.087185	0.094393	0.101852	0.109546	0.117460	0.133879
25	0.078227	0.085811	0.092679	0.101806	0.110168	0.127500

the graph was prepared. This technique is also demonstrated in the example (Table 20).

Within the size range of plants covered by this document, O&M costs will rise slowly with increasing plant size. A very small plant costs almost as much to run as one 2-3 times larger. With respect to O&M costs, there are considerable economies of scale in larger plants and new/ expanded facility planning should take advantage of this where possible.

Package Gravity Filters

O&M costs include building energy based on housing floor area and assuming that all equipment is enclosed. Process energy is for filter supply, backwash and surface wash pumping. Maintenance material costs were estimated from operating facilities and include replacement of washed out media, small parts, recorder ink/paper for controls and instruction, and other supplies required to operate the filters. Administrative and laboratory supplies and general facility maintenance are not included. Chemical costs are not included. Labor costs assume that the filter will not be attended full time. Typically, such systems are attended for 8 to 12 hours/day, operating on automatic controls otherwise.

Table 17 presents O&M cost data for filtration rates of 2 and 5 gpm/sq.ft. (81.5-203.7 lpm/sq.m.). Figure 36 is the associated O&M cost curve.

Package Pressure Diatomite Filters

O&M data were developed from manufacturer data and are representative of minimum operating requirements. Process energy is for filter and hold pumps, mixers and other items associated with the filter system. Backwashing every 24 hours was assumed. Maintenance materials include spare parts, and general facility supplies but do not include chemicals and

Table 17
Operation and Maintenance Summary for Package Gravity Filter Plants[15]

Plant Capacity (gpm)	Energy(kw-hr/yr)			Maintenance Material ($/year)	Labor (hr/yr)	Total Cost* ($/year)
	Building	Process	Total			
Filtration rate of 2gpm/sq.ft. (81.5 lpm/sq.m.):						
80	153,900	3,950	157,850	1,070	2,920	35,010
140	184,680	6,920	191,600	1,280	2,920	36,230
225	184,680	11,064	195,740	1,390	3,650	43,760
280	184,680	13,830	198,510	1,600	3,650	44,060
560	360,000	27,660	387,660	2,670	4,380	58,100
Filtration rate of 5 gpm/sq.ft. (203.7 lpm/sq.m.):						
200	153,900	9,470	163,370	1,070	2,920	35,170
350	184,680	16,580	201,260	1,280	2,920	36,520
560	184,680	26,250	210,930	1,390	3,650	44,220

* Calculated using $0.03/kw-hr and $10.00/hr of labor.

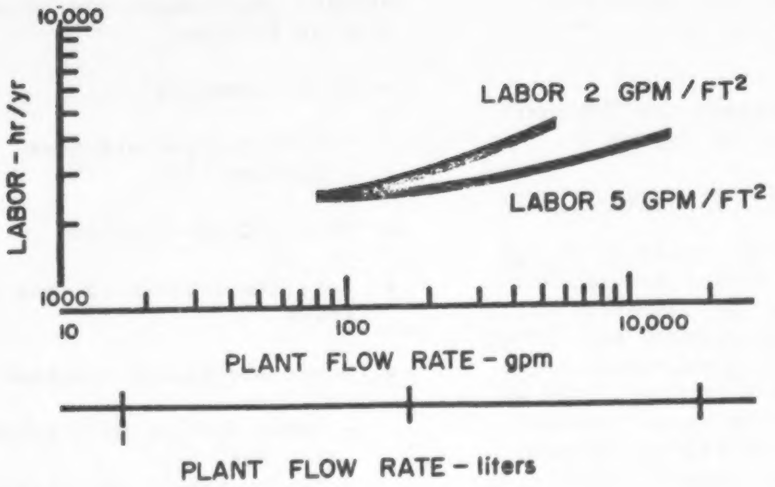

Figure 36. Annual Labor Hours for Package Gravity Filters[15]

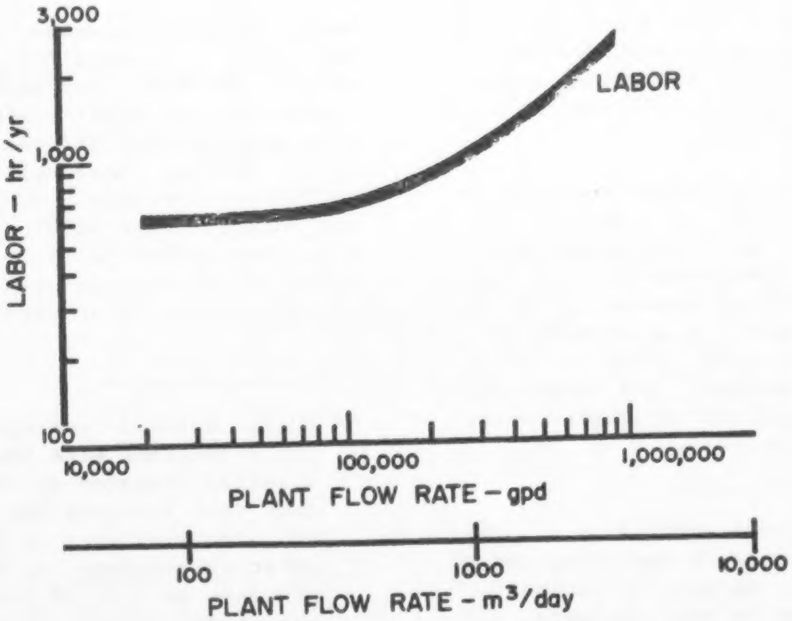

Figure 37. Annual Labor Hours for Packaged Pressure Diatomite Filters[15]

diatomaceous earth.* Labor costs assume that the filter operates with little attention except for preparation of precoat and body feed, chemical feed adjustment, and product water quality monitoring.

Table 18 summarizes the O&M costs used in developing Figure 37.

Package Complete Treatment Plants

O&M costs include building energy for a totally housed system, and process energy for operation of rapid mix, flocculators and filter washing pumps. Maintenance material costs, based on experience at typical operating installations, include spare parts, replacement media and other general suppliers. Administrative and laboratory services, chemicals and general facility maintenance are not included.

Operator time includes that needed for adding chemicals and adjusting feed rates, performing routine quality control laboratory work, and carrying out daily maintenance and housekeeping.

Cost data is provided for filtration flow rates of 2 and 5 gpm/sq.ft. (81.5-203.7 lpm/sq.m.). Table 19 summarizes the cost data used to develop Figures 38 and 39. Table 20 provides an example of how capital, O&M, total annual cost of treatment, and total cost per 1000 gallons of treated water can be calculated.

FUNDING SOURCES**

The principal financing options to small water systems for treatment process improvement can be categorized as follows:

- Self Financing
  - User charges and fees
  - Bonding/loans
- Direct Grant Programs
- Subsidized/Assisted Loan Programs
- Other Assistance Programs
  - Labor sharing with other systems
  - EPA technical assistance activities

These are discussed in turn below:

Self Financing

Water utilities process, deliver and charge consumers for potable water. In this, they bear close resemblence to other businesses that also produce and sell a product. Most of these utilities, publicly or privately owned, do not normally have problems in financing needed capital improvements either through user fees or changes in the water rate, or by

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* Diatomaceous earth is a significant expense in operating these filters. Be sure to include this cost in your estimate.

** NOTE: Federal financial assistance programs were under substantial revision at the time that this document was prepared. You will need to reconfirm existing programs and check for new ones as part of your financing study.

Table 18
Operation and Maintenance Summary for Package Pressure Diatomite Filters[15]

Plant Flow Rate (gpd)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/year)	Labor (hr/yr)	Total Cost* ($/year)
28,000	26,700	1,380	28,080	$150	700	$ 7,990
86,000	28,700	4,140	32,840	250	750	8,740
140,000	31,800	6,900	38,700	300	900	10,460
280,000	47,200	13,800	61,000	400	1,100	13,230
560,000	51,300	27,600	78,900	550	1,500	17,920
1,000,000	77,100	51,740	128,840	750	2,900	33,620

* Calculated using $0.03/kw-hr and $10.00/hr of labor.

NOTE: 1 gpd = 0.003785 cu.m./d

Table 19
Operation and Maintenance Summary for Package Complete Treatment Plants[15]

Plant Capacity (gpm)	Energy(kw-hr/yr) Building	Process	Total	Energy Cost	Maintenance Material ($/year)	Labor (hr/yr)	Cost	Total Cost* ($/year)
Filtration Rate of 2 gpm/sq.ft.:								
4	30,780	320	31,100	$ 930	$ 320	1,460	$14,600	$15,850
8	38,780	390	39,170	1,170	590	1,460	14,600	16,360
40	61,560	3,210	64,770	1,940	860	1,750	17,500	20,300
80	98,500	3,950	102,450	3,070	1,600	3,200	32,000	36,670
140	174,420	6,920	181,340	5,440	1,920	3,600	36,000	43,360
225	184,680	11,060	195,740	5,870	2,140	3,600	36,000	44,010
280	277,020	13,830	290,850	8,730	2,570	3,600	36,000	47,300
560	410,400	27,660	438,060	13,140	3,210	5,400	54,000	70,350
Filtration Rate of 5gpm/sq.ft.								
10	30,780	780	31,560	950	320	1,460	14,600	15,870
20	38,780	1,560	40,340	1,210	590	1,460	14,600	16,400
100	61,560	7,810	69,370	2,080	860	1,750	17,500	20,440
200	98,500	9,470	107,970	3,240	1,600	3,200	32,000	36,840
350	174,420	16,580	191,000	5,730	1,920	3,600	36,000	43,650
560	184,680	26,520	211,200	6,340	2,140	3,600	36,000	44,480

* Calculated using $0.03/kw-hr and $10.00/hr of labor.

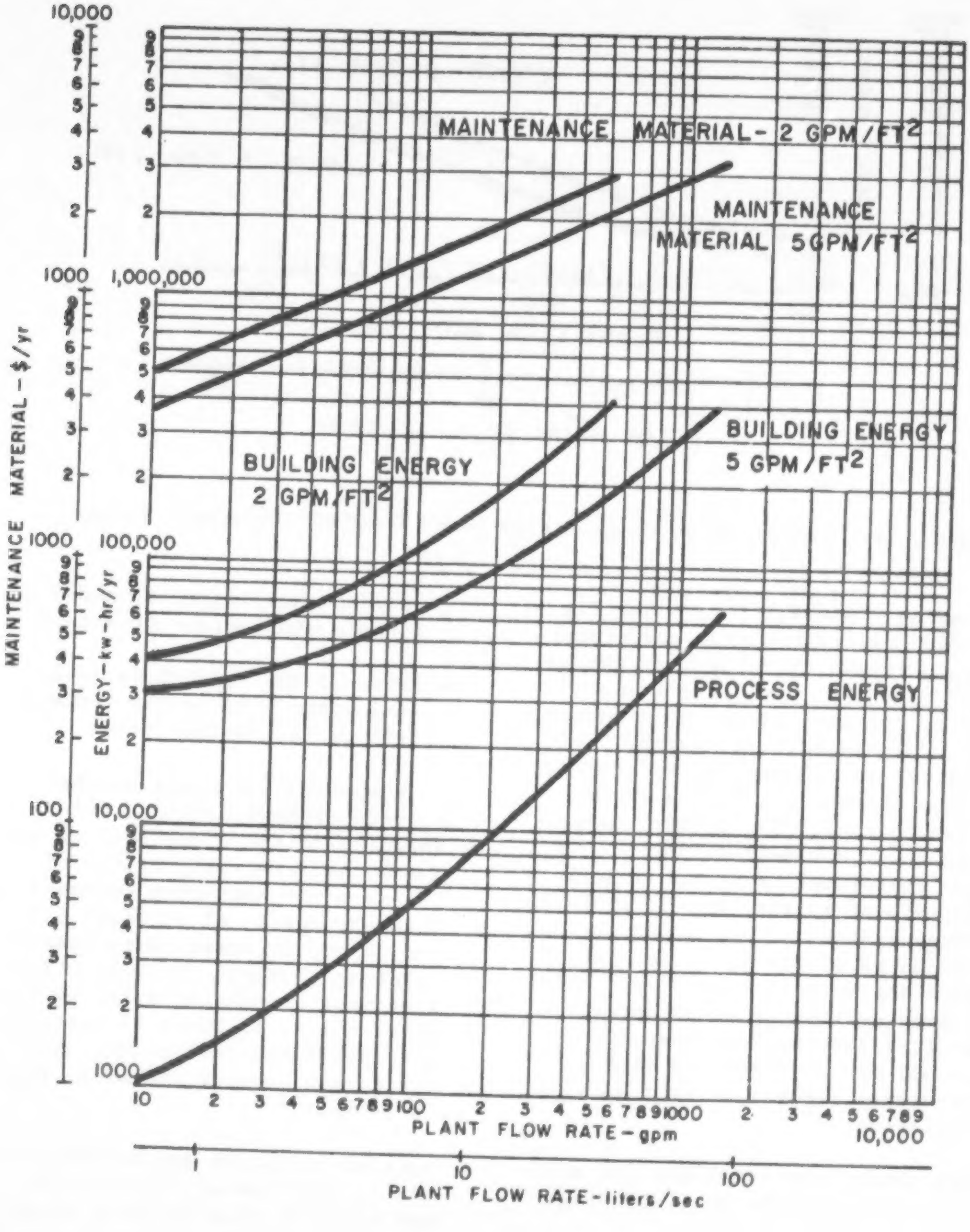

Figure 38. Operation and Maintenance Cost of Packaged Complete Treatment Plants - Building Energy, Process Energy and Maintenance Material[15]

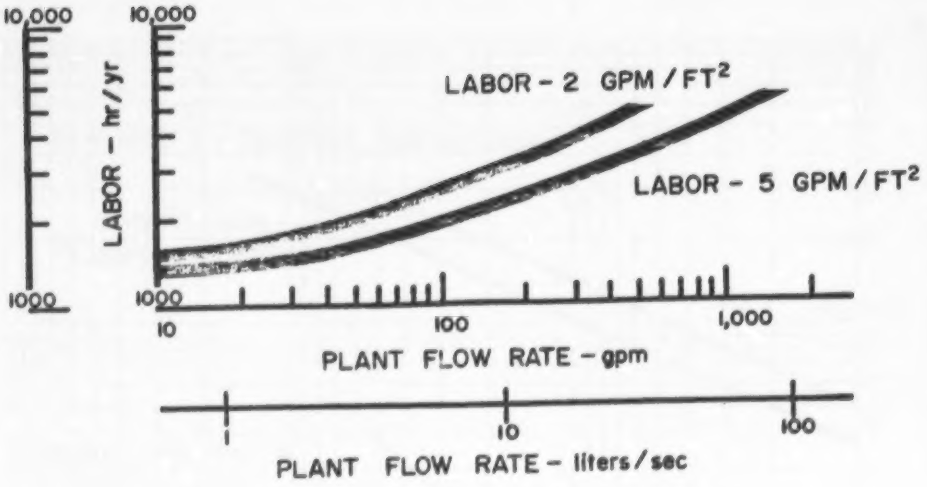

Figure 39. Annual Labor Hours for Packaged Complete Treatment Plants

bonding. However, the financing needs for constructing and operating a turbidity removal system may severely strain small community water systems, either by requiring capital expenditures beyond their ability to finance, or by causing large incremental increases in user charges. The latter course may incur consumer resistance to the improvement program, a major impediment in the case of publicly owned systems. Very small systems may be particularly vulnerable to problems in this regard--one study indicates that up to 30 percent of systems serving less than 500 people may be unable to finance turbidity removal without outside assistance.[26]

The prime considerations for self-financing include the following:

- Amount of revenues available for payment of interest costs
- Ratio of new treatment capital costs to existing assets
- Percent rate increase needed to finance and operate treatment
- Ratio of the typical residential water bill to the community's median family income

In competing for funds on the private capital markets, the larger utility is expected to have a debt service ratio (ratio of income after operating expenses to interest costs) of at least 1.3 and income at least twice that of interest charges. Private utilities must be showing a net profit, after taxes, of 10 to 13 percent. User bills should run less than 1.5 to 2.0 percent of median family income.[22]

Smaller utilities may be substantially less robust financially, and still be able to raise money locally. Utility customers may be willing and able to put up the needed capital. Even so, the utility should have a debt service ratio of at least 1.0 so interest and bond repayment schedules can be met.

Grant Programs

The principal financial assistance program available to small community water systems (public or private nonprofit) is operated by the Farmers Home Administration (FmHA) of the Department of Agriculture. FmHA can grant up to 75 percent of the cost for installation, repair or upgrading of community water systems that serve fewer than 10,000 people and meet certain median income criteria. The emphasis is on farmers and other rural residents.

Program aid priorities are as follows:

- Public bodies and towns with emphasis to those serving 5,500 people or less
- Assist compliance with Safe Drinking Water Act
- Low income communities receive preference

(1) User charges must be at least equal to other similar, already established systems, on the basis of:

  - Similar costs of contruction and operation
  - Similar economic conditions

(2) Debt service costs exceed net levels as determined by the ratio of mean family cost for water service to median family income. Specifically:

  - For communities of median family income less than $6,000, debt service must exceed 0.75 percent of median family income to be eligible.
  - For communities of median family income, $6,000 to $10,000, debt service/income must exceed 1.0 percent for eligibility.
  - For communities exceeding $10,000 median family income, debt service/income must exceed 1.25 percent for eligibility.

FmHA can be contacted for further information at any one of 340 offices nationwide.

The Economic Development Administration (EDA) has some limited programs for water/sewer assistance, primarily keyed to promoting industrial development and employment and creation of jobs. Grants can range from 50 to 80 percent of project costs (up to 100 percent for Indian Tribes) and public or private nonprofit agencies may qualify. EDA has six regional offices and staff in each of the 50 states.

The Department of Housing and Urban Development (HUD) has a program of Community Development Block Grants (CDBG) that are administered locally and used for a wide variety of community improvement projects. You can apply for funding through city and/or county governments in which your system is located.

Direct Loan Programs

Three federal agencies operate direct loan programs:

- Department of Interior - has two programs available to public nonfederal entities in the 17 western states.

- Farmers Home Administration - has loan program with similar criteria to those used in their grant program. The loan can be for 100 percent of the project cost.

- Small Business Administration - has a number of loan programs that may be used by small investor-owned water utilities. Loans cannot exceed $150,000.

Loan Guarantee Programs

Both the Small Business Administration (SBA) and the Farmer's Home Administration (FmHA) can provide backing for privately placed loans as follows:

- SBA - will guarantee up to 90 percent of a loan up to $500,000 for private, independent businesses that are refused a bank loan.

- FmHA - has a Business and Industry Loan Program available to public or private organizations, particularly those located in rural areas and serving fewer than 2,500 persons. Loan guarantees range up to 90 percent of face value.

Other Forms of Assistance

Other ways of reducing financing and/or operating costs include the following:

- Bond banks - Several states have central bond banks that assist localities in the mechanics of bond financing. By aggregating small bonds into larger ones, interest costs may be reduced and bond placement enhanced.

- State loan programs - Several states provide direct loans for construction of public water and sewer projects. The programs are normally operated under the aegis of state economic development offices.

- Shared operation costs with other nearby utility(s) - Regionalization is one approach to shared operating expenses.

Table 20
Sample Cost Analysis for a 140 gpm Complete Treatment Plant

STEP 1: Calculate Cost Adjustment Factors as of June, 1982.

A. Construction Cost Escalation Factor (CCEF)

$$\text{Construction Cost Escalation Factor (CCEF)} = \frac{\text{Current ENR CCI}}{\text{Base ENR CCI}}$$

The cost curves of Reference 15 are based on October, 1978, costs, when the ENR Construction Cost Index (CCI) stood at 265.38. The June, 1982, ENR CCI was 352.92.

$$\text{Therefore, CCEF} = \frac{352.92}{265.38} = 1.33$$

B. Maintenance Material Cost Escalation Factor (MMCEF)

$$\text{Maintenance Material Cost Escalation Factor (MMCEF)} = \frac{\text{Current PPI}}{\text{Base Year PPI}}$$

The October, 1978, Producer Price Index (PPI) issued by the U.S. Department of Commerce, was 199.7. The June, 1982, PPI was 299.4.

$$\text{Therefore, MMCEF} = \frac{299.4}{199.7} = 1.50$$

STEP 2: Estimate Construction Cost Using Figure 34.

From Figure 34, Construction cost in October, 1978, dollars, is $190,000 for a 140 gpm plant with a 2 gpm/sq.ft. filter rate.

June 1982 Construction Cost = $190,000 x CCEF

= $190,000 x 1.33 = 252,700

From Figure 35, Construction cost in October 1978 dollars, is $6000 for a 30,000 cubic foot (852.3 cubic meter) sludge storage lagoon for process wastewater storage.

June 1982 Constr. Cost = $6000 x CCEF

= $6000 x 1.33 = $7980

Total Construction Cost = $252,700 + $7900 = $260,680

(Continued)

Table 20
Sample Cost Analysis for a 140 gpm Complete Treatment Plant

STEP 3: Estimate Annual O & M Cost

A. Maintenance Material

From Figure 38, October, 1978, annual maintenance material cost is $1,600.

June 1982 = $1,600 x MMCEF
Maintenance Materials Cost
= $1,600 x 1.50 = $2,400

B. Energy Cost

Energy Use = Process Energy + Building Energy*

From Figure 38,

Energy Use = 150,000 kwh/year + 7,000 kwh/year

= 157,000 kwh/year

$$\text{Energy Cost/Year} = \text{kwh/year} \times \frac{\text{energy cost}}{\text{kwh}}$$

For this example, assume energy cost of $0.05/kwh

Energy Cost/Year = 157,000 x $0.05

= $7,850

C. Labor Cost

From Figure 39, Labor, hr/year = 3,000. If labor costs $12 per hour (including fringe costs), annual labor cost is calculated as follows:

$$\text{Annual Labor Cost} = 3{,}000\ \frac{\text{hours}}{\text{year}} \times \$12/\text{hour}$$

= $36,000

D. Total O&M Cost

Total O&M Cost = Maintenance Material Cost + Energy Cost +
Labor Cost

= $2,400 + $7,850 + $36,000 = $46,250

---

* Building energy is very dependent on climate. If possible, estimate this directly for your area.

(Continued)

Table 20
Sample Cost Analysis for a 140 gpm Complete Treatment Plant

STEP 4: Annualize Construction Cost

If the cost of money is 10 percent, and the system has a 20 year design life, the annual equivalent of the construction cost is as follows:

$$\text{Annual Capital Equivalent} = \text{Capital Cost} \times \text{Capital Recovery Factor, 10 percent, 20 years}$$

The capital recovery factor from Table 16 for 10 percent and 20 years is 0.117460.

$$\text{Annual Capital Equivalent} = \$260{,}680 \times 0.117460$$

$$= \$30{,}620 \text{ per year}$$

STEP 5: Sum Annual Costs of Construction and O&M and Determine Cost per 1,000 Gallons Treated*

A. Annual Cost Summary

Capital	$30,620
Operation and Maintenance:	
Maintenance Materials	2,400
Energy	7,850
Labor	36,000
Total	$76,870

B. Annual Treated Flow, Thousands of Gallons

$$\text{Annual Treated Flow (1000 gallons)} = 140 \text{ gpm} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{1}{1000} \times 365$$

$$= 73{,}584$$

C. Cost per 1000 gallons treated**

$$\text{Cost/1000 gallons} = \frac{\text{Annual Cost}}{\text{Annual Treated Flow (1000 gallons)}}$$

$$= \frac{\$76{,}870}{73{,}584 \text{ (1000 gallons per year)}}$$

$$\text{Cost/1000 gallons} = \$1.045$$

---

* This does not include chemical costs which are specific to the water being treated.

** This does not include waste disposal costs other than the annualized capital cost of the lagoon.

VI. OPERATION AND MAINTENANCE

Packaged water treatment systems will provide long, low maintenance service if properly cared for. The equipment does not normally require continuous operator supervision because of control systems which monitor turbidity levels and automatically adjust coagulant dosage and filter backwashing. Preventive Maintenance (PM) is the key to long, trouble free performance. This section of the Manual sets out recommended monitoring and PM activities for a typical small packaged complete treatment or direct filtration water treatment plant.

OPERATOR REQUIREMENTS

Operation of a packaged water treatment plant does not require unusual operator skills. However, the operator should be reasonably expert in basic plumbing and electrical skills and should understand the operation and repair of simple pumps, valves, water meters and controls. He or she must be capable of carrying out a program of periodic sampling and be able to use a Nephelometric Turbidity Test Meter, make simple calculations and keep organized legible records. He/she must be able to conduct jar tests and must understand and be able to apply the basic principles of coagulation chemistry. The operator should be of sufficient intelligence and schooling to understand the fundamentals of process operation and be able to attain state certification where required.

Operator time requirements are dependent on system size. However, it is not likely that he or she will spend more than one regular shift per day monitoring and maintaining the plant.

MANUALS, EQUIPMENT AND SUPPLIES NEEDED

Provide the system operator with the service manuals, tools, analytical equipment and supplies needed to properly maintain the system. For example:

- System maintenance manual for each individual piece of equipment and the system as a whole.
  - Startup, test, routine (preventive) maintenance, trouble shooting guide.
  - Schedule of routine maintenance activities and tools/supplies for each task. The schedule should be laid out on a daily, weekly, monthly, quarterly and annual basis as needed.
  - Sources, including name, address and telephone numbers, for emergency parts and service. This should also be posted near the equipment.
  - Operational directions, including detailed control settings for electrical controls, motorized valves, flowmeters, pumps, etc.
  - Sampling and test procedures and schedules for process monitoring and reporting to the state.

  - Appropriate sample forms for recording maintenance procedures and water quality data. Format of recommended record keeping.

- Recommended tools and critical spare parts for each item, such as lubricants, valve and pump gaskets and packing, electrical fuses. Stock key spare parts that are not available locally or overnight from manufacturer's warehouse.

- Test Equipment for Process Control

  - Alkalinity
  - Turbidity
  - pH
  - Chlorine

- Supply of coagulating and pH adjustment chemicals.

STARTUP TRAINING AND ASSISTANCE

A trained representative of the manufacturer should be present when starting up a packaged water treatment system. He should train your operators and check the equipment out fully. Normally, this should require several weeks time and the cost of this service should be included in the price of the equipment. The manufacturer should also provide a detailed service manual for the equipment.

MONITORING

Monitoring encompasses two activities:

(1) Monitoring to satisfy regulatory requirements

(2) Monitoring for process control

Regulatory requirements (see page II-5) for turbidity require you to monitor and record turbidity data daily. Table 3, on page II-6, is a form which can be used for recording turbidity data. The form allows you to calculate and record the 2 day average turbidity as well.

Remember that the turbidimeter should be calibrated before each series of tests, at least once daily. Also, standard solutions must be periodically replaced. Obtain replacement standards from the instrument manufacturer or a nearby certified laboratory unless you have the equipment and personnel to prepare them in-house.

Monitoring for process control requires use of the turbidity meter to check the operation of the automatic control system. A daily check is recommended. Analyze influent and effluent turbidities and compare them with the data logged by the automatic monitor. If the variation exceeds that called for in the service manuals, check and adjust the system as specified. Your plant should be equipped with continuous reading turbidimeters for both raw and finished water turbidities. These should be equipped to sound alarms or other indicators in the event of major changes in turbidity. For example, the raw water turbidimeter for a system whose water averages 5 NTU might be set to automatically sound an alarm if a 10 NTU level is exceeded. The treated water turbidimeter should sound an alarm if turbidity exceeds 1 NTU.

As coagulating chemicals may affect finished water pH, this should also be checked daily, at the same time that turbidity is checked. Use a pH test kit or portable pH meter for this check.

COAGULATION CONTROL AND MONITORING

As part of the process study and design process, your engineers will have characterized the raw water supply characteristics and performed sufficient jar tests and other analyses to select the primary coagulant(s), coagulant aids (polymers), and approximate dosage ranges. It is the job of the plant operators, during the first few months after plant startup to "fine tune" the coagulant system by developing a control and monitoring scheme that suits your particular raw water and treatment plant.

Setting up a coagulant control program that works for your system includes the following steps:

- **Operator training:** Enroll operators in state, local college[27] and/or professional association (such as AWWA) training courses that stress treatment plant operation and coagulation control. If a packaged plant is used, make sure that the supplier includes onsite operator training in his bid. Plan on a continuing effort in operator training which includes additional training annually, and subscriptions to trade publications. Contact the American Water Works Association, 6666 W. Quincey Avenue, Denver, Colorado 80235, for a listing of their current manuals and training aids for small water systems and obtain those which suit your situation.
- **Review Nearby Plant Practices:** Quite possibly, there are other plants nearby treating the same raw water supply. Find out about these from your state health department or state water supply agency and spend some time talking with their operators to find out their experience.
- **Consult the Chemical Manufacturer:** Chemical suppliers are an excellent source of applications expertise. Ask your coagulant supplier about any literature, training aids, trouble shooting assistance or other services available from his firm.
- **Conduct Jar Testing:** Conduct a series of jar tests for your raw water over its range of condition. Find out how much coagulant and polymer is needed for the high and low range of turbidities (such as might occur after a heavy rain or during extended low flow periods). Use the jar test to determine the optimum pH for your coagulation system and develop a scheme for pH monitoring and control. Over a period of time you will develop a body of data which, when combined with operator observations, can be used to set up a coagulant control scheme. Figure 40 is an example of a graph that you might prepare as a guide for coagulation control.

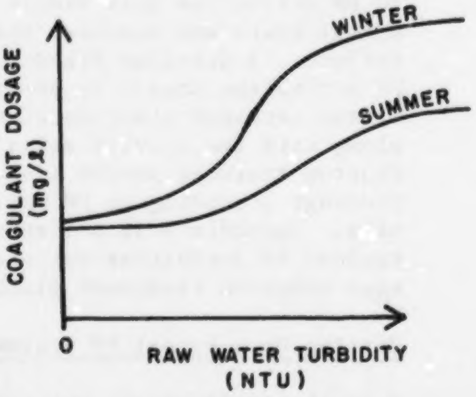

Figure 40. Sample Coagulant Control Curves

If your plant is equipped with automatic coagulation control equipment you can use the steps above to set up the operating program for the controller. A properly set up automatic control system can reduce the need for continuous supervision of the coagulating process. IT IS NOT A SUBSTITUTE FOR DIRECT OPERATOR SUPERVISION. Coagulation is a critical process in the water treatment scheme and needs to be given close attention by plant operators.

The water quality monitoring instruments, particularly those for pH and turbidity, are the "eyes" of your coagulation control system. Set up a separate checking and maintenance program, in accordance with manufacturers' recommendations, for these important instruments. At least twice daily, check the continuous turbidimeter readings against samples tested on your laboratory turbidimeter and make appropriate adjustments and/or repairs.

PREVENTIVE MAINTENANCE

Preventive maintenance (PM) is the key to reliable service and long equipment life. Close attention to PM activities will reduce annual costs and minimize system failure. A detailed schedule of PM activities should be provided by the packaged plant manufacturer along with the service manual. Startup training should include a thorough grounding in PM activities. Appendix D is a listing of typical PM activities for a packaged complete treatment plant.

Setting Up a Formal PM System

Even the smallest water treatment plants may have numerous pumps, mixers, drivers, controls, meters, etc., each with its own maintenance requirements. You can set up a simple maintenance schedule and recordkeeping system which will help manage the preventive maintenance function. Also, it is useful as a management tool to identify where your time (and money) is being spent and spot failure prone system components.

The first step is to develop an inventory of each piece of plant equipment you wish to cover in the PM system. In general, any equipment directly involved in the treatment plant process with moving parts requiring periodic maintenance should be covered. Figure 41 is an example of an equipment inventory sheet that could be used. Each piece of equipment is assigned a number which is used on all records. The number is painted onto the equipment as well.

For each item on the equipment inventory, a Maintenance Data Form, shown in Figure 42, is set up. This form records pertinent data on the item such as its model and serial numbers, installation date, location, power requirements, and a record of maintenance actions taken on it. This is an extremely useful form as it can show you at a glance the history of a piece of equipment. Numerous entries closely spaced in time may indicate that a particular piece of equipment is failure prone and should be replaced or modified.

There are three main sources of maintenance data which can be used to develop the plant PM system:

- Equipment Manuals
- The Equipment Manufacturer
- Experience of Plant Operators

(1) Equipment Number	(2) Equipment Name	(3) Type of Equipment	(4) Location of Equipment

Figure 41. Equipment Inventory Sheet

NOTES: (1) Equipment number - use any number of series of numbers that will uniquely identify the equipment. The number should also be painted conspicuously on the equipment.

(2) Name as given in the plant specification or as given by the manufacturer.

(3) Describes briefly the equipment function and power source.

(4) Provides sufficient detail for finding the equipment readily.

(A) Front Side

Equipment Name and Number	Type	Location	
Manufacturer	Local Representative	Part or Model Number	Serial Number
Reference Drawing	Reference Catalog	Introduction Book	Date Put in Service

Electric Motor			Pump			Drive or Reducer		
HP	Frame	RPM	Capacity	TDH	RPM	HP	RPM In	RPM Out
Volts	Amps	Phase	Impeller		Packing	Ratio		

Type	Specifications	Type	Installation	Type
☐ Series	☐ Open	☐ Centrifugal	☐ Horizontal	☐ Gear
☐ Shunt	☐ Exp. proof	☐ Plunger	☐ Vertical	☐ V-Belt
☐ Synchronous	☐ Drip proof	☐ Diaphragm	☐ Submerged	☐ Chain
☐ Introduction	☐ Totally enclosed	☐ Gear	Lubrication	☐ Varidrive
☐ ________	☐ ________	☐ Screw	☐ Water	
		☐ ________	☐ Oil	
			☐ Grease	

Bearings ☐ Sleeve ☐ Ball ☐ Roller	Bearings ☐ Sleeve ☐ Ball ☐ Roller	Bearings ☐ Sleeve ☐ Ball ☐ Roller
Lubricant	Lubricant	Lubricant

Other Equipment

Type, Speed, Size, Capacity, Range

Bearings, Lubricant

Other Features

(b) Reverse Side

CORRECTIVE MAINTENANCE WORK RECORD

Date	Mechanic's Name	Reg. Hrs.	OT Hrs.	Parts or Mtls.	Manufacturer and Catalog No.	Cost

Describe what was found wrong and how it was fixed

Recommendation for avoiding repeated failure

Outside Contractor Used

Reason

Actual Costs
- Labor ________
- Parts ________
- Contractors ________
- Total ________

Equipment Status of Completion
- Fully operational
- Non-operational
- Reduced capability
- Awaiting spare parts

Spare Parts Availability
- In stock
- Obtained locally
- Delay in procurring
- Length ________

Total Down-Time

Work Completed
Date ________ Maint. Foreman ________

Work Accepted
Date ________ Requestor ________

Figure 42. Equipment Data Sheet

This data can be compiled in the form of a maintenance procedures sheet (MPS) as shown in Figure 43, which lists the specific steps and spare parts needed to carryout a specific maintenance activity. You will need one of these for each identifiably distinct maintenance action on a piece of equipment. They can be tied together in a numbering system which is coordinated with the plant inventory listing. For example, equipment item 10 might have 4 associated maintenance procedure forms, numbered 10-01, 10-02, 10-03, and 10-04. These forms would be kept in sequence in a book or file for ready access and reference by maintenance personnel.

There are two main types of maintenance activity: Routine (periodic) preventive maintenance (PM), and repair maintenance. The former is carried out on a regular schedule, the latter is performed on equipment that has broken down or is expected to fail shortly. You will need to prepare and follow a PM schedule, an example of which is shown in Figure 44. One of these is prepared for each week of the year and includes daily, weekly and periodic PM activities. Figure 45a is the form used to report trouble and request needed repair. When a maintenance action is carried out, either for PM or for repair, it is reported on the back of the malfunction report form (Figure 45b). In turn, this data is entered on the permanent record for the equipment item (Figure 42).

You should give serious consideration to setting up a PM system for your plant. It can be a valuable management tool for tracking O&M activities and associated costs. Too, the improved equipment maintenance that results from the use of a PM system will prolong equipment life and cut repair costs. This in turn, can lead to more consistent, higher quality water production.

EMERGENCY PROCEDURES

Should excessive turbidity break through the final filter, the system should be shut down immediately and the filter backwashed. Before restarting, check for over accumulation of sludge in the settling chamber and check and adjust chemical feed as needed. After returning the unit to service, check and calibrate turbidity monitors and verify that turbidity standards are being met. Diagnose the cause of the failure and modify operating procedures to prevent a reoccurrence. Observe all State regulatory requirements regarding notification and monitoring.

SAFETY PROCEDURES

Owners of packaged water treatment systems that use coagulation should take normal safety precautions where strong chemicals are used. An emergency shower and eye wash fountain should be provided adjacent to the chemical mixing area. A washing hose and floor drain should be provided in the chemical treatment section of the plant. Operators should wear protective gloves and face shields when handling chemicals, particularly those used for pH adjustment. Provide adequate ventilation and a high capacity exhaust fan that can be turned on to quickly clear out dusts and vapors from chemicals.

		(1)
MAINTENANCE PROCEDURE SHEET	Page 1 of 1	MPS
Equipment Name and Number		
Plant Area Location		
Maintenance Description (2)		
Safety Precautions		
Tools, Parts, Materials, Test Equipment		
Procedure		

Figure 43. Maintenance Procedure Sheet

NOTES: (1) The MPS Number should include the equipment number plus a number or letter for the MPS. For example 1-A, 1-B, 1-C might refer to a series of MPS for a given piece of equipment.

(2) Should include a reference to any maintenance manuals for the piece of equipment.

Equipment Name/No.	Maintenance Action	MPS No.	(1) Frequency

Figure 44. Weekly Preventive Maintenance Schedule

NOTES: (1) Frequency is either:
D - Daily
W - Weekly
P - Periodic, performed only when listed on the weekly schedule

(a) Front Side

CORRECTIVE MAINTENANCE WORK REQUEST

Date	Requested by	Required Completion Date
Equipment Name and Number		Location

Indication of Trouble
- ☐ Broken Part
- ☐ Worn Part
- ☐ Heat
- ☐ Noise
- ☐ Smell
- ☐ Vibration
- ☐ Leaking
- ☐ Other ______________
- ☐ Dirty, fouled
- ☐ Voltage
- ☐ Current
- ☐ Assistance
- ☐ Flow rate
- ☐ Pressure
- ☐ Speed

When Discovered
- ☐ Starting
- ☐ Stopping
- ☐ During Operation
- ☐ During PM
- ☐ During CM
- ☐ During MOD
- ☐ During ON
- ☐ Other ______________

Cause of Trouble
- ☐ Heat/cold/weather
- ☐ Humidity/moisture
- ☐ Foreign object
- ☐ Shock/vibration
- ☐ Wear
- ☐ Equipment defect
- ☐ Improper installation
- ☐ Improper lubrication
- ☐ Improper operation
- ☐ Other ______________

Corrective Work Requested ______________

Estimated Costs
Labor ______________
Parts ______________
Contractors ______________
Total ______________

Estimated Down-Time

Approved by	Date	Job No.

(B) Reverse Side

PARTS LIST

Name of Part	Manufacturer	Cat. No.	Local Supplier	Cost

Figure 45. Report of Trouble/Corrective Action Form

VII. CASE HISTORIES

CARLISLE, PENNSYLVANIA

The Carlisle Suburban Authority, located in south central Pennsylvania, serves a current population of 4,500 outside of the town of Carlisle with water and sewer services. The Authority operates a combined water treatment and waste water treatment/disposal plant located adjacent to Conodoqumet Creek, in the eastern suburbs of Carlisle.

The Creek is typical of many medium sized eastern streams draining areas which have both extensive agricultural and industrial development. Turbidity, which averages 4 NTU, can exceed 200 NTU after significant rainfalls. pH ranges from 6.5 to 7.8. Extended dry periods may cause the stream to dwindle to a trickle. By the time that the stream reaches Carlisle, it has received effluents from a number of domestic and industrial sources.

The treatment plant uses two complete treatment packaged plants operated in parallel, each of 280 gpm (17.7 l/s) capacity with the mixed media filters operating at their design capacity of 5 gpm/sq. ft. (203.7 lpm/sq.m.). The packaged plants feature flash mixing of the alum and polyelectrolyte coagulants followed by flocculation in horizontal paddle mixed flocculators of 17 minutes detention time. (Figure 46)

Tube settlers in each unit of 105 sq.ft. face area (9.75 sq.m.), loaded at 2.6 gpm/sq.ft. (106 lpm/sq.m.) settle the flocculated water before it enters the mixed media filters. Each mixed media filter has 56 sq.ft. (5.2 sq.m.) of surface area and includes facilities for high rate backwashing and surface washing. The plant engineers elected to use a programmable solid state digital controller for automatic backwash control instead of the mechanical system normally provided by the manufacturer of the package plant. The reason cited for this change was that the electronic controller gave the plant operators far greater flexibility in varying filter cycles.

Alum is the primary coagulant, supported by a polyelectrolyte coagulant aid. Alum is normally added at a rate of 12-23 mg/l with polyelectrolyte added at 1% of this rate. A small quantity of a filter aid polymer is also added to extend filter runs and improve performances. Powdered activated carbon is added into the filter head tanks for taste and odor control at the beginning of each filter cycle (12 hours). The plant is operated 5 days per week, 12 hours per day with two shifts of operators.

Construction of the plant immediately adjacent to the sewerage treatment plant has allowed the Authority to combine their operation, with considerable cost savings. Both plants use liquid alum, stored at the sewage plant. A staff of four operators and a superintendent run both plants and maintain the system's distribution and collection piping, pumping stations, fire hydrants and water meters. Wastes from the water treatment plant are discharged to an equilization tank below the floor of the water plant and

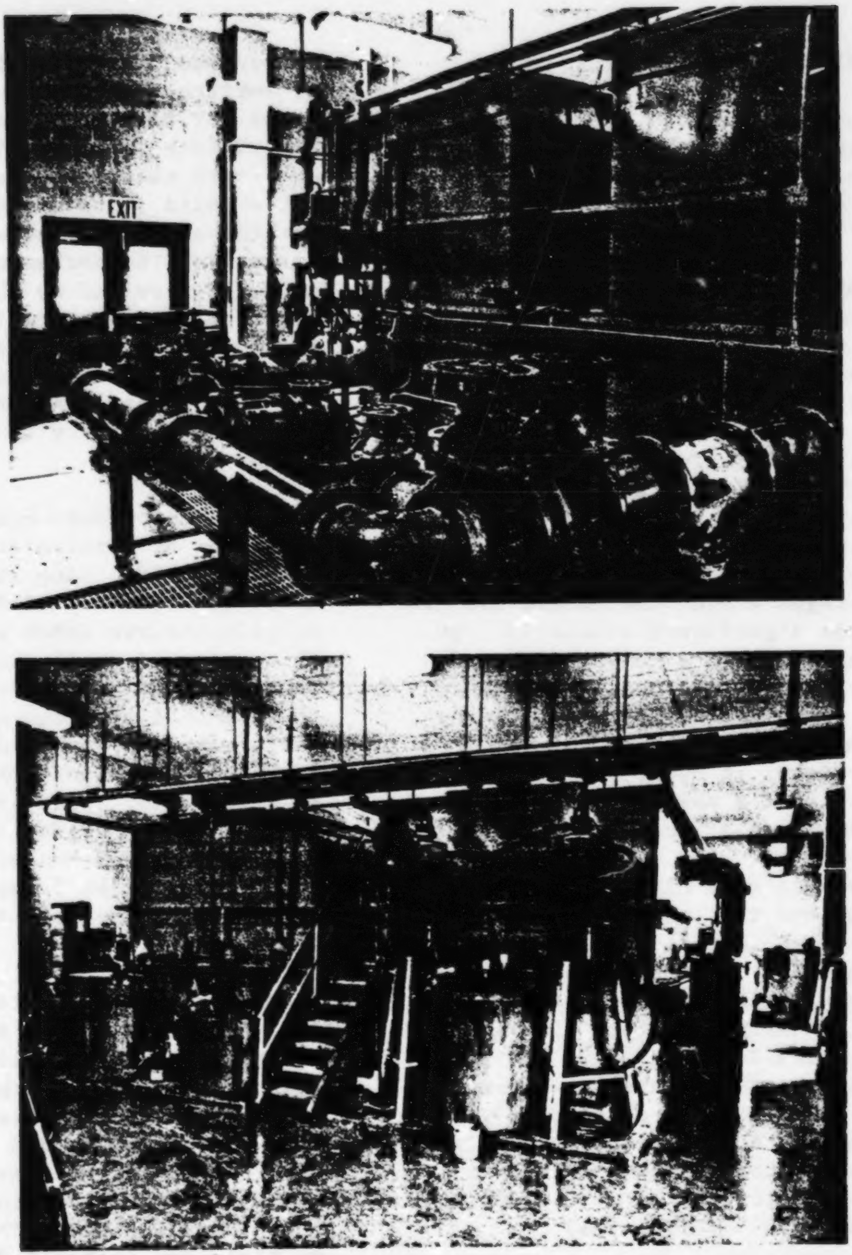

Figure 46. Carlisle, PA Packaged Complete Treatment System

gravity fed continuously to the headworks of the sewage treatment plant. Provision has also been made to skim the supernatant from the holding tank for recycle to the water treatment plant during drought conditions. Plant operators report that the water treatment sludge has had a significant beneficial impact on the operation of the wastewater treatment plant.

The two plants also share a joint control room/laboratory which features centralized monitoring and control of all equipment and processes. The compact and functional design maximizes shared facilities and operator efficiency. Laboratory space is ample and well laid out (Figure 46).

This plant is an excellent example of the combination of good equipment and design, with conscientious operation. Chemical mixing and feeding equipment is well located and accessible to operators. Provision has been made for quick and easy cleanup of chemical spills. Control and monitoring equipment is highly visible and easy to work on.

The packaged treatment plants were supplied by a leading U.S. manufacturer with extensive experience in water treatment. The opportunity to integrate water and wastewater treatment and support facilities has been maximized, with close attention given to protecting the water supply. The operators were given extensive startup training, and there is a continued commitment to training, averaging 1 week per year per man. The specification of high quality materials and construction for both buildings and equipment is evident, and conscientious housekeeping and maintenance is practiced by plant operators who appear to have substantial pride in the plant.

After several months for startup and shakedown, plant operators reported that operation has been almost trouble free. The polyelectrolyte metering and feed pumps was found to be undersized and was replaced with a larger unit. Some trouble was experienced in learning the operation of the backwash controller. Also, operators have found the controls for shutting down either of the two parallel units to be somewhat inconvenient.

The plant is consistently producing highly clarified water, averaging 0.3 NTU or less in turbidity. When the adjacent Town of Carlisle water treatment plant suffered a major breakdown, Carlisle Suburban operated their system 24 hours per day at 60% over the design flow rate, successfully meeting the emergency without seriously lowering the quality of the finished water.

The water treatment portion of the system was constructed in 1978-79 at a cost of $634,540 for general construction and $179,730 for electrical work (Table 21). The packaged treatment plants and appurtenant chemical mixing and feeding equipment cost $133,190. The plant was formally placed in service in December of 1979.

HANCOCK, MARYLAND

Hancock, Maryland, located in the western part of the state, upgraded and expanded an existing treatment system with a packaged complete treatment system. The 560 gpm (35.3 l/s) plant was installed in October 1979 to treat surface waters from the Little Conoloway Creek. Raw water turbidity averages 5 NTU but can rise to very high levels after a rainfall. Figure 47 is a photograph of the interior of the plant

Table 21
Carlisle Suburban Authority, Pennsylvania Plant Data

Manufacturer/Model	Neptune Microfloc Aquarius 112
Rated Capacity (2 parallel units)	560 gpm (35.5 l/s)
Raw Water Data:	
Turbidity, NTU	4 to 200
pH	6.5 - 7.8
Alkalinity mg/l	150
Finished Water	
Turbidity	0.3 - 0.4
pH	7.5
Chemical Feed Rate (avg. Conditions)	
Alum, mg/l	17-23
Polyelectrolyte mg/l	0.17-0.23
Lime	As needed to adjust pH to
7.5 as needed for taste and Activated Carbon	odor control
Filter aid (polymer)	Trace
Filters	
Type	Mixed Media
Area, each filter	56 sq.ft. (5.2 sq.m.)
Design Loading	5 gpm/sq.ft. (204 lpm/sq.m.)
Cost	
Package Plant and Chemical Mix/Handling	$133,190
Total Facility, including equipment, installation, and housing (Engineering and legal fees not included).	$634,540

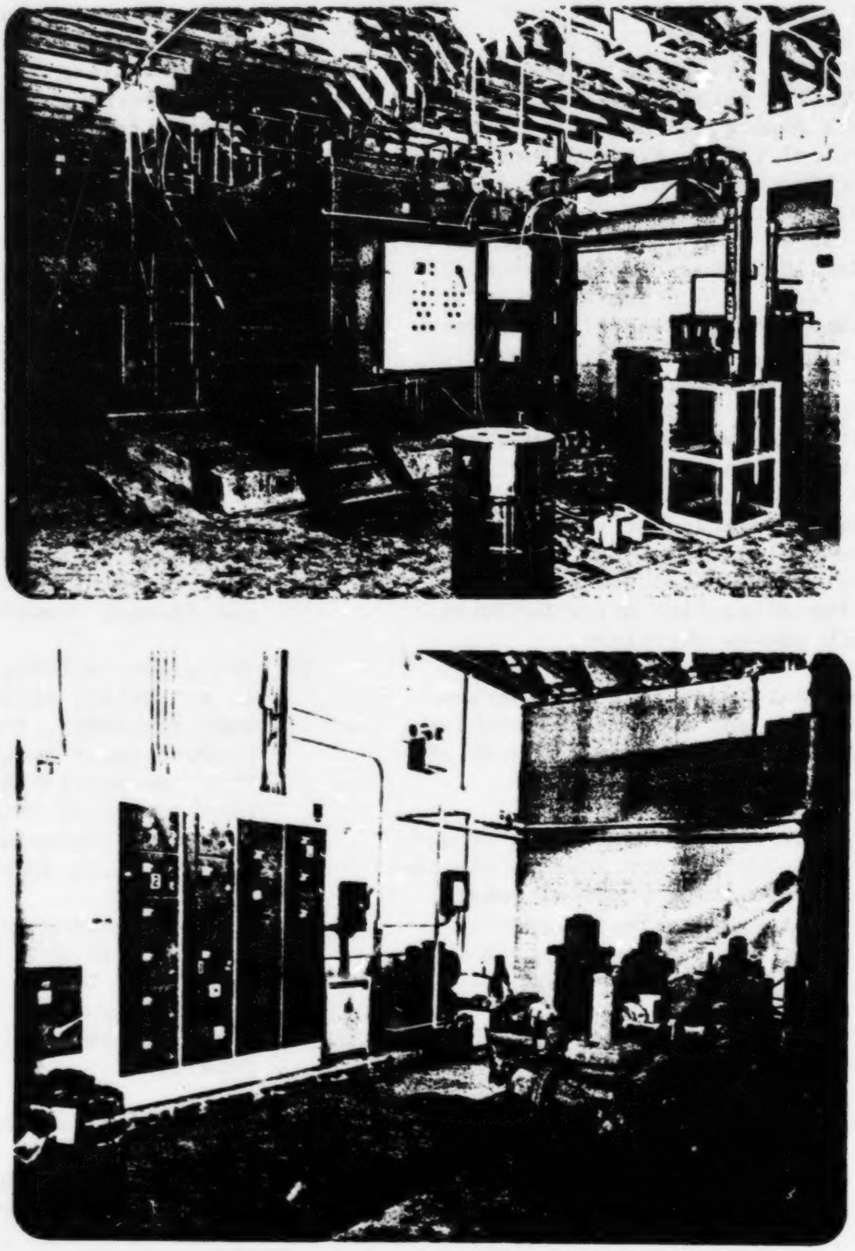

Figure 47. Hancock, MD Packaged Complete Treatment System

housing, showing the controls and chemical mixing/metering system. Alum and polyelectrolyte are used for coagulation.

The water treatment process features two parallel sections with rapid mixing, flocculation with vertical paddle flocculators, parallel plate settlers, and dual media filters. The filters have 18 inches of 0.45 to 0.55 mm sand under 12 inches of anthracite and are rated at 4.6 gpm/sq.ft. at design flow (Table 22). The backwashing system includes provision for air scouring. Alum sludge is disposed by land spreading and filter backwash water is sewered although the plant has provision for recycling this stream. Wet well for storage of finished water, alum sludge and backwash water are located under the floor of the attractive brick building which houses the plant.

The plant has experienced severe equipment and operational problems since startup. These are some of the most significant:

(1) The calibration curves provided for the operator to use in correlating chemical dosage are apparently incorrect. The settings on the chemical feed pumps are not accurate.

(2) The raw water supply is highly variable in quality. No provision was made to level out the variability (i.e., a presettling pond). No equipment has been provided to automatically monitor the raw water quality and alert the operator to large fluctuations. Hence, chemical feeding is often incorrect, causing high loading to the filters.

(3) The plant was originally provided with a rotary microscreen for flocculated solids removal. This equipment failed and was replaced with parallel plate settlers. Plant operators indicated great difficulty in desludging the settlers and the settler wet well.

(4) Due to frequent failure of the chemical addition system, solids are not being effectively removed by the flocculation/settling step. This causes solids overload of the filters, resulting in the need to backwash the filters more often than anticipated in the original design. About 20,000 gallons per day of ground water is being used to wash both filters twice per 16 hour running day.

(5) The plant is being operated on a 2 shift, 16 hour day. When restarted, the initial product water is quite turbid. No provision has been made to bypass this water to prevent degradation of the treated water supply.

(6) It is necessary to shut down the plant to stop the raw water feed to the chemical injection pumps. This increases the difficulty of repair.

(7) The chemical injection pumps supplied with the packaged treatment system have been inaccurate and unreliable. No nearby source of service or parts is available and the plant does not stock spare parts or a spare pump.

(8) The air scour backwash system causes cratering in the

Table 22

Hancock, Maryland Plant Data

Manufacturer/Model	Paddock Refinite
Rated Capacity (2 parallel units)	560 gpm (35.5 l/s)
Raw Water Data:	
Turbidity, NTU	4 to 10 avg, over 200 maximum
pH	7.5
Alkalinity mg/l	165
Finished Water	
Turbidity	1 or greater
Flow (1514-1892 cu.m/d)	400,000 to 500,000 gpd
Chemical Feed Rate	
Alum	Unknown
Polymer	Intermittent
Filters	
Type	Dual Media
Media	
Sand 0.45 to 0.55 mm	18 inches (45.5 cm)
Anthracite	12 inches (30.5 cm)
Area, each filter	60.5 sq.ft. (5.6 sq.m.)
Design Loading	4.6 gpm/sq.ft. (187 lpm/sq.m.)
Cost	
Package Plant and Equipment	$229,657
Building and Wet Wells	$180,444

filter bed. Air flow solenoid valves regularly stick and must be rapped sharply to be operated.

The plant operators have expressed dissatisfaction with the start-up service and training provided on the project. Operation and maintenance of the chemical feed system was singled out as the major problem area. Also, the lack of automatic turbidity monitoring control on a highly variable water supply is a problem as there is only one operator normally on duty during each shift and he has numerous other duties which require leaving the plant for short periods of time.

Recently, the town retained an outside engineering consultant to diagnose the plant's problems and recommend remedial measures.

DIRECT FILTRATION--17 PLANT SURVEY

Culp[19] reported data from a questionnaire directed at 100 direct filtration plants. The 17 responding plants ranged in size from 0.5 mpd to 200 mgd. The following data was reported:

- Average raw water turbidity was less than 25 in all of the plants, but 20 percent of the plants treated water that exceeded 100 NTU at times.
- Seven plants used single stage rapid mix, six used two stage, and mixing time varied from 15 seconds to 5 minutes. One did not report.
- Eight plants used flocculation, nine did not.
- Fourteen plants used dual or mixed media; three used sand or coal single media. Thirteen plants used gravel media supports.
- Filtration rates ranged from 2-5 gpm/sq.ft. Backwash rates ranged from 8-22 gpm/sq.ft. Ten plants had filter bed surface washing. The average filter run between cleanings was 5-8 hours.
- Five plants add alum alone, 6 plants add alum and a polymer, three add only polymer. Three did not report.
- Eight plants had continuous turbidity meters.

The reference also provides a partial listing of direct filtration plants.

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APPENDIX A

ABBREVIATIONS AND SYMBOLS

ft -- foot
sq.ft. -- square foot
cu.ft. -- cubic foot
gal -- gallon
gpd -- gallons per day
gpd/sq.ft. -- gallons per day per square foot
gpm -- gallons per minute
hr -- hours
kw-hr -- killowatt-hour
l -- liter
lb -- pound
lpm/sq.m. -- liters per minute per square meter
lpd -- liters per day
lpd/cu.m. -- liters per day per cubic meter
lps -- liters per second
mm -- millimeter
cm -- centimeter
m -- meter
sq.m. -- square meter
cu.m. -- cubic meter
cu.m./d -- cubic meters per day
cu.m./s -- cubic meters per second
mg/l -- milligrams per liter
mgd -- million gallons per day
min -- minutes
psi -- pounds per square inch
tu -- turbidity unit
cu.yd. -- cubic yard
yr -- year

METRIC-ENGLISH CONVERSION FACTORS

English Unit	Multiplier	Metric Unit
sq.ft.	0.0929	sq.m.
cu.ft.	0.028	cu.m.
cu.yd.	0.75	cu.m.
in	2.53	cm
ft	0.3048	m
gal	3.785	l
gal	0.003785	cu.m.
gpd	0.003785	cu.m./d
gpm	0.0631	l/s
gpm/sq.ft.	40.74	lpm/sq.m.
gpd/sq.ft.	40.74	lpd/sq.m.
mgd	0.0438	cu.m./s

APPENDIX B [5]

SAMPLE TURBIDITY METER SPECIFICATION

DETAILED SPECIFICATIONS
for the
NEPHELOMETRIC TURBIDIMETER

The following specifications will help you select your turbidimeter:

The turbidimeter shall consist of a nephelometer, with a light source for illuminating the sample, and one or more photoelectric detectors, with a readout device to indicate the intensity of light scattered at right angles to the path of the incident light. The turbidimeter shall be so designed that little stray light reaches the detector in the absence of turbidity and shall be free from significant drift after a short warm-up period.

The sensitivity of the instrument should permit detection of turbidity differences of 0.02 unit or less in waters having turbidities less than 1 unit. The instrument should measure from 0 to 40 units turbidity. Several ranges will be necessary to obtain both adequate coverage and sufficient sensitivity for low turbidities.

The sample tubes to be used with the available instrument must be of clear, colorless glass. They should be kept very clean, both inside and out, and discarded when they become scratched or etched. They must not be handled at all where the light strikes them, but should be provided with sufficient extra length or with a protective case for handling.

Differences in physical design of turbidimeters will cause differences in measured values of turbidity even though the same suspension is used for calibration. To minimize such differences, the following design criteria should be observed:

- Light source: Tungsten lamp, operated at not less than 85 per cent of rated voltage or more than rated voltage
- Light path: Distance traversed by incident and scattered light within the sample tube not to exceed 10 cm total
- Detector light-acceptance angle: Centered at 90 degrees to the incident light path and not to exceed ± 30 degrees from center.
- Maximum turbidity to be measured: 40 units.

The Hach turbidimeter, models 2100 and 2100-A, and the H. F. instruments DRT-100 have been found acceptable; other instruments meeting the above design criteria also are acceptable.

APPENDIX C

JAR TEST PROCEDURE

(Courtesy, Phipps & Bird, Inc.)

COAGULATION TEST

Every rapid sand filter plant should be equipped with apparatus for conducting coagulation tests, commonly called "jar tests." In its simplest form, the only apparatus required to perform this test is a series of six glass jars, stirring rod, pipettes, pH test equipment, and standard solutions of coagulant and alkali (or acid). The jars may either be 1 qt. or 1 gal. capacity; the latter are preferred. Although hand stirring is quite satisfactory for an occasional test, a mechanical stirring device is far more satisfactory and gives better results. In carrying out the test, the jars are filled with freshly drawn water and solution [and the alkali (acid) solution if necessary] beginning with a small dose in the first jar and increasing throughout the series. The chemicals are added rapidly and the treated water is stirred vigorously for 3 min. and slowly for 15 min. and is then allowed to subside quietly for 3 hr. or more.

The quantities of the chemicals applied are chosen in accordance with the results of the preliminary physical and chemical tests and the experience of the operator in the coagulation of water. In the absence of such experience, the test will have to be repeated and numerous doses and combinations of doses used until the minimum dosage can be determined with which satisfactory coagulation can be secured. In judging coagulation the following criteria should be used:

1. The first appearance of floc.
2. The appearance of floc in (a) 5 min., (b) 30 min.
3. The appearance of the supernatant liquid and the settleability of the floc at the end of a period of time corresponding to the retention period of the plant sedimentation basin.
4. The effect of filtration may be ascertained by filtering a portion of water from each jar through plugs of absorbent cotton and determining the color and turbidity of the filtrate.

In conducting the jar test, it is important that the temperature of the water in the jars be maintained at approximately the same temperature as when the samples were taken. A pH determination on the water in each jar must be made 5 min. after the preliminary mixing is completed. All observations made during the test should be recorded on a sheet similar to the example given below.

From this information, it is apparent that a dosage of 1.0 gpg of alum, without the addition of alkali, is close to the optimum for this particular sample of water and that a pH of 6.4 should be maintained on the water in the mixing chamber. On a plant scale a dosage of 0.9 gpg at a pH 6.6 should give good results. This is a simple example; in ordinary practice, numerous conditions will occur that require several trials before the optimum is secured. It often happens that the amount of coagulant required to produce the optimum pH of coagulation is far in excess of that necessary completely to clarify. In this case the only value of the excess alum is its acidity, and the alum is wasted. It is possible to treat such waters successfully and economically with a combination of alum and sulphuric acid, and jar tests are made with standard solutions of these chemicals in the same manner as described above. Naturally a process involving the use of sulphuric acid has numerous disadvantages and requires careful chemical control.

TEST EXAMPLE

Raw Water at 7 a.m.		Date	
Color	10	Alkalinity	45
Turbidity	50	pH	7.0
Temperature	60° F	Free CO_2	9

JAR TEST EXAMPLE

Jar No.	Alum added g.p.g.	Lime added p.p.m.	First Floc	5 min.	30 min.	5 hr.	pH
1	0.5	0	None	....	....	....	6.9
2	0.6	0	10 min.	Smoky	Smoky	Smoky	6.9
3	0.7	0	5 min.	Fair	Fair	Fair	6.8
4	0.8	0	2 min.	Fair	Good	Good	6.7
5	0.9	0	1 min.	Good	Good	Excellent	6.6
6	1.0	0	1 min.	Excellent	Excellent	Excellent	6.4

In the case of those waters for which excessive quantities of alum or the use of acid is required to reach the optimum, ferric compounds have a useful field, for they can be coagulated either in a low or a high pH range. Because alum can be used only in a low pH range–usually less than 7.0–it is apparent that the filtered water will be corrosive and that this condition will have to be corrected following filtration. Iron coagulation at high pH prior to filtration can be designed to correct for corrosion so that no further adjustment of the filtered-water reaction is necessary. In cases where the raw water contains undesirable amounts of iron or manganese or both, the iron-coagulation process is plainly indicated.

When the chemical doses that are most effective for a given raw-water condition have been determined in the laboratory, it is up to the operator to adjust the chemical feeds until the best floc is obtained, using the pH results obtained from the jar tests as a guide. The ability to tell whether the dosage is satisfactory or not is largely a matter of experience, but the following suggestions will be helpful to the novice:

1. The quality of the floc in the mixing chambers and the sedimentation basins, as well as the appearance of the filter influent, should be observed hourly by the operator. A submerged waterproof light is useful for this.
2. With rapidly fluctuating raw waters or those in which good coagulation is difficult to maintain, a quart jar of water from the mixing chamber should be taken every hour, the pH recorded, and the jars preserved in a row upon a table until eight have been collected. These samples form a continuous historical record of the coagulation process and serve to prove to each successive shift operator and the superintendent that the operator responsible for them has performed his duty faithfully and well.
3. In a well-coagulated water, the particles of floc are distinct and well formed, and the water should show numerous clear spots between the particles. After 5 or 10 min. settling in a jar, particles of floc at the center of the jar should be clearly visible when viewed sidewise through the liquid.
4. A cloudy or smoky appearance of the treated water indicates incorrect dosage.

As the experience of the operator increases, he will require fewer jar tests. He will learn to recognize recurring conditions and handle them from past experience. Careful records of previous operations and graphs relating to turbidity and color and to coagulant requirements under different conditions of temperature and alkalinity are very valuable. As has been stated earlier, the coagulation process is the heart of the rapid sand process. Failure to give constant attention results in a poor product, filter deterioration, waste of chemicals and thoroughly unsatisfactory conditions.

APPENDIX D

PREVENTIVE MAINTENANCE FOR AQUARIUS A SERIES COMPLETE TREATMENT PLANT

(Courtesy, Neptune Microfloc Corporation)

PLANT MAINTENANCE

GENERAL

Procedures for plant maintenance may vary from plant to plant, but good housekeeping rules should apply anywhere. The following are some general suggestions:

Dust from chemicals should be cleaned up at once and not allowed to build up on floors, pumps, valves, instruments, etc.

CAUTION: Alum in solution with water lowers the pH, that is, acid conditions are formed. Alum dust combined with a little moisture can become quite corrosive to equipment, metals, and finishes and should be cleaned up and wiped or washed off at once.

WARNING: POLYELECTROLYTE MIXED WITH A LITTLE WATER OR MOISTURE FORMS A VERY SLIPPERY FILM. SPILLED CHEMICAL SHOULD BE CLEANED UP AT ONCE AND THE FLOOR CLEANED AND DRIED IF CHEMICAL WAS WETTED IN ANY WAY. THE FLOOR SHOULD BE CHECKED AND SAND OR OTHER MATERIAL TO PREVENT SLIPPING INJURIES SHOULD BE SPREAD TEMPORARILY.

Chemical storage areas should be kept as clean as possible to prevent chemical dust from creating health or maintenance problems.

WARNING: THE CHEMICALS USED IN WATER TREATMENT REQUIRE SOME PRECAUTIONS FOR STORAGE AND HANDLING. PRODUCT SAFETY INFORMATION FOR CHEMICALS IS INCLUDED AT THE END OF THE INSTRUCTION SECTION OF THIS OWNER'S MANUAL.

Moisture should not be allowed to accumulate on electrical equipment or devices.

Electrical equipment should not be subjected to direct water hose pressure and indirect splashing should be minimized during plant wash-down and clean up.

Water should not be allowed to stand on floors or accumulate anywhere.

WARNING: ONLY QUALIFIED PERSONNEL SHOULD WORK ON ELECTRICAL EQUIPMENT.

A regular schedule of cleanup and maintenance should be planned and followed to insure long equipment life and promote trouble-free plant operation.

A plant operation and maintenance log should be set up and filled out on a regular basis.

The following suggested procedures should be included in your maintenance schedule but are not meant to be the complete schedule.

CAUTION: The maintenance schedule should include all recommendations in the equipment manufacturer's instructions included in the Equipment Data section of the Manual.

PLANT MAINTENANCE

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The following suggested procedures should be included in your maintenance schedule but are not meant to be the complete schedule.

CAUTION: The maintenance schedule should include all recommendations in the equipment manufacturer's instructions included in the Equipment Data section of the Manual.

DAILY

1. Check chemical feeders for correct operation and calibration. Suction lines must be free of air. Strainers should be clear of sediment. Feed lines and connections should be free of leaks.

2. Check and maintain an adequate supply of chemical solution in the chemical feed tanks.

NOTE: Chemical feed charts and mixing instructions are included at the end of the Instruction Section of the Manual.

CAUTION: Remember chemical treatment is the most important step in water treatment. Without chemicals, essentially untreated raw water goes into your finished water storage.

3. Make a general inspection of the entire plant observing operation and condition of all equipment.

4. Drain accumulated moisture from any non-automatic condensate traps in the air lines.

5. Check and record water quality (turbidity, pH, chlorine, color, etc.) and note any operational problems. Record chemical dosages including any changes in feed rate and the reasons and results of same.

NOTE: Records of operating condition changes are valuable to anticipate and make adjustments in your operation for changes in the raw water characteristics because of seasonal changes or due to storms. A sample Weekly Operating Report log sheet is included with these instructions.

WEEKLY

1. Check the function and adjustment of all of the plant equipment according to the manufacturer's recommendations and the Operation Instruction section of this Manual. Manufacturer's instructions are in the Equipment Data section of this Manual and maintenance recommendations should be included in your log.

2. Check oil levels in the chemical feed pumps and in the flocculator drive gearbox. The recommended oil specifications are in the manufacturer's instructions in the Equipment Data section.

3. Plant flow rate and especially the splitting of the raw water flow, one half the flow to each section of the plant, should be observed at least once a week. If you do not have raw water flow instrumentation, an indication of the flow splitting would be by the valve disc position indicator on the two effluent valves. Valve discs should be open the same and the out-put gauges on the level controllers should read about the same pressure with clean filters after a backwash of both filters.

4. This would be a good time to get the filters clean and, at the same time, observe the complete backwash cycle. The cycle can be initiated with the "Automatic Backwash Manual Initiate" switch on the plant controller.

Check the functioning and speed of opening of the waste valve. The water level in the tube clarifier should drop at about two feet per minute. Check the speed of opening of the backwash valve.

NOTE: Refer to the Equipment Adjustment for Backwashing and Backwash Cycle in the Operation and Maintenance section of the Manual for the complete description of adjustments that should be checked.

5. Inspect the filter media surface and the tubes in the tube clarifier. Agitate the media with a rake if there appears to be an accumulation of floc that was not washed out during the backwash cycle. The media should be clean after the next cycle. Re-agitate if it is not. A clean filter will run longer between backwash cycles and should save finished water.

   Wash any accumulation of sludge from the tube modules with a low pressure hose.

CAUTION: Do not use a high pressure fire hose to wash out the filter or to clean the tube modules.

   The NMI Technical Director will demonstrate these cleaning procedures during plant startup.

6. Check the coagulant feed rate and floc formation in the two flocculator compartments.

   Raw water conditions may change and you may want to run some jar tests to check the effectiveness of the alum feed rate and make some adjustments. Settling tests of the floc coming out of the flocculator can help judge the effectiveness of any changes. RECORD any CHANGES in CHEMICAL FEED and the raw water conditions, season, storm conditions, etc., at the time of the change. These records can help you make adjustments to your plant for similar conditions in the future without having to redo the jar tests.

NOTE: The Chemical Treatment and Coagulation, Mechanically Powered Flocculation, and Chemical Feed sections of the Operation and Maintenance instructions have guides to checking coagulant feed rate.

MONTHLY

1. Drain chemical mixing tanks and clean out any chemical sludge in the bottom of the tanks.

   Check chemical feed pumps, lines, check valves, and strainers for any accumulation of chemical residue. Clean or flush the pumps according to the manufacturer's recommendations.

NOTE: Chemical feed pump manufacturer's maintenance instructions are in the Equipment Data section of the Manual.

2. Observe and check the functioning of all automatic valves. Follow any manufacturer's recommendations for maintenance of actuators and positioners.

CAUTION: Lack of maintenance of air lines, filters and compressor/dryer cause most valve actuator problems. Dirt or moisture in the compressed air supply are the most frequent cause of automatic valve malfunction.

3. Check the functioning of the level controller in the filter compartment. The water level should be at about the middle hole in the controller mounting bracket. Check the functioning of the limit switches.

NOTE: Level controller adjustment is covered in the Plant Operation section of the Manual under Equipment Adjustment for Filtering, Backwashing.

4. Observe and check the headloss switch adjustment. The switch should start a backwash cycle automatically when the headloss gauge reads 7-8 feet of water headloss.

5. All pumps should be checked for leaks at the seals and for overall function. Motor bearings should not be noisy.

6. Flocculator drive motor should not have noisy bearings. Brushes should be checked for remaining wear life.

7. Filter agitators should rotate freely by hand and rotate automatically during the backwash cycle.

8. Adjust or repair anything found in the equipment checks according to the manufacturer's recommendations.

9. Review records of the months operation. A brief summary with comments on unusual operational conditions or problems can be valuable and save you time when similiar conditions occur in the future.

10. The overall plant should give the appearance of good housekeeping. It is easier to keep it clean than it is to clean it up later.

YEARLY

1. Drain each section of the plant separately. One section can stay online.

2. Clean out any accumulatin of sludge in the flocculator and tube clarifier compartments.

3. Check the flocculator rotors for broken or misaligned paddles. Check the bearings.

4. Check the settling tube modules for tube pagesses that may be plugged with sludge. Check for damage to the tube modules.